U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-250 825

COMPREHENSIVE EVALUATION OF ENERGY CONSERVATION MEASURES

APPENDICES

MATHEMATICA, INCORPORATED

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

MARCH 1975

KEEP UP TO DATE

Between the time you ordered this report—which is only one of the hundreds of thousands in the NTIS information collection available to you—and the time you are reading this message, several *new* reports relevant to your interests probably have entered the collection.

Subscribe to the **Weekly Government Abstracts** series that will bring you summaries of new reports *as soon as they are received by NTIS* from the originators of the research. The WGA's are an NTIS weekly newsletter service covering the most recent research findings in 25 areas of industrial, technological, and sociological interest—invaluable information for executives and professionals who must keep up to date.

The executive and professional information service provided by NTIS in the **Weekly Government Abstracts** newsletters will give you thorough and comprehensive coverage of government-conducted or sponsored research activities. And you'll get this important information within two weeks of the time it's released by originating agencies.

WGA newsletters are computer produced and electronically photocomposed to slash the time gap between the release of a report and its availability. You can learn about technical innovations immediately—and use them in the most meaningful and productive ways possible for your organization. Please request NTIS-PR-205/PCW for more information.

The weekly newsletter series will keep you current. But *learn what you have missed in the past* by ordering a computer **NTISearch** of all the research reports in your area of interest, dating as far back as 1964, if you wish. Please request NTIS-PR-186/PCN for more information.

WRITE: Managing Editor
5285 Port Royal Road
Springfield, VA 22161

Keep Up To Date With SRIM

SRIM (Selected Research in Microfiche) provides you with regular, automatic distribution of the complete texts of NTIS research reports *only* in the subject areas you select. SRIM covers almost all Government research reports by subject area and/or the originating Federal or local government agency. You may subscribe by any category or subcategory of our WGA **(Weekly Government Abstracts** or **Government Reports Announcements and Index** categories, or to the reports issued by a particular agency such as the Department of Defense, Federal Energy Administration, or Environmental Protection Agency. Other options that will give you greater selectivity are available on request.

The cost of SRIM service is only 45¢ domestic (60¢ foreign) for each complete microfiched report. Your SRIM service begins as soon as your order is received and processed and you will receive biweekly shipments thereafter. If you wish, your service will be backdated to furnish you microfiche of reports issued earlier.

Because of contractual arrangements with several Special Technology Groups, not all NTIS reports are distributed in the SRIM program. You will receive a notice in your microfiche shipments identifying the exceptionally priced reports not available through SRIM.

A deposit account with NTIS is required before this service can be initiated. If you have specific questions concerning this service, please call (703) 451-1558, or write NTIS, attention SRIM Product Manager.

This information product distributed by

NTIS U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

078023
PB 250 825

EPA-230/1-75-004

COMPREHENSIVE EVALUATION OF ENERGY CONSERVATION MEASURES

FINAL REPORT

Appendices

Prepared for

U.S. Environmental Protection Agency
Office of Planning and Evaluation
Washington, D.C.

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

March 1975

TECHNICAL REPORT DATA PAGE	1. Report No. EPA-230/1-75-004	2.	3. Recipient's Accession No.
4. Title and Subtitle: COMPREHENSIVE EVALUATION OF ENERGY CONSERVATION MEASURES--APPENDICES			5. Report Date: March, 1975 6.
7. Author(s): Limaye, Sharko, Price, Orlando, Wander, Oelschlager, Hunt, Wright, Schlosser, Hyder			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: Mathematica Inc. Philadelphia, Pa. and Peat, Marwick, Mitchell Washington, D.C.			10. Project/Task/Work Unit No. 11. Contract/Grant No. EPA 68-01-2440, 2445
12. Sponsoring Organization Name and Address: Office of Planning and Evaluation, Environmental Protection Agency, Washington, D.C. 20460			13. Type of Report & Period Covered: Final 14.

15. Supplementary Notes

Reproduced from best available copy.

16. Abstracts

Appendices to the final report of the same title (EPA-230/1-75-003) provide detailed methodology, data base and technical discsussions.

17. Key Words and Document Analysis. 17a. Descriptors

Energy conservation
Social impact analysis
Environmental impact analysis
Economic analysis
Cost-benefit analysis methodology

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 1-3
	20. Security Class (This Page) UNCLASSIFIED	22. Price $6.00

*U.S. GOVERNMENT PRINTING OFFICE 1974 582-413/67 1-3

COMPREHENSIVE EVALUATION OF ENERGY CONSERVATION MEASURES

-APPENDICES-

Prepared for

Office of Planning and Evaluation

United States Environmental Protection Agency

Under EPA Contracts

68-01-2445

and

68-01-2440

Project Officer

Margaret J. Tifft

Office of Planning and Evaluation

APPENDIX A

BASELINE ENERGY DEMAND PROJECTIONS

MATHEMATICA

BASELINE ENERGY DEMANDS

This appendix summarizes the various sector energy consumption projections used in the estimation of the maximum potential energy savings. These projections are associated with the conservation measures considered in this research effort and, therefore, do not cover the total energy consumed in the U.S. This appendix places these projections in the context of the total energy consumed in the U.S.

The consumption of each form of energy by each sector are given for 1960, '65, and '70 in figures A-1 through A-3. These figures were generated by the MATHEMATICA Energy Data Base Retrieval Program with the MATHEMATICA Energy Data Base serving as the source of the data. The MATHEMATICA Energy Data Base was compiled from information from various government and private organizations such as the Bureau of Mines, the Federal Power Commission, and the Edison Electric Institute. The data shown in figure A-1 through A-3 are available for the entire period 1960-1972. All of the data on bituminous coal, natural gas, electricity, residual oil, distillate oil, diesel fuel, gasoline, jet fuel, kerosine and LPG are available on a state and census region basis for 1960-1972.

A comparison of the energy consumption effected by the various energy conservation measures considered in this report is given in figure A-4. The details of the calculation of the 1970 energy consumption for each section is given in figures A-5 through A-8.

FIGURE A-1

TOTAL ENERGY CONSUMPTION
SOURCE: MATHEMATICA ENERGY DATA BASE

YEAR...1960 TYPE OF ENERGY	HOUSEHOLD & COMMERCIAL N.P.	HOUSEHOLD & COMMERCIAL R.M.	INDUSTRIAL N.P.	INDUSTRIAL R.M.	TRANSPORTATION	POWER GENERATION	MISCELLANEOUS	TOTAL
					(TRILLION BTUS)			
COAL								
-ANTHRACITE	0	0	0	0	0	0		
-BITUMINOUS	813	0	4635	0	25	3929	447	447
GAS							0	9400
-HEAT & POWER USE	4254	0	6503	0	358	1780	282	13180
-CARBON BLACK	0	0	0	204	0	0	0	204
-OTHER CHEM. FEEDSTOCK	0	0	0	167	0	0	0	167
PETROLEUM PRODUCTS								
-GASOLINE	0	0	0	0	7933	0	0	7933
-JET FUEL	0	0	0	0	582	0	0	582
-DISTILLATE	2403	0	468	0	886	27	42	3980
-RESIDUAL	789	0	1271	0	825	536	39	3461
-KEROSINE	447	0	114	0	0	0	0	562
-LIQUID GASES	403	0	55	359	85	0	5	911
-STILL GASES	0	0	776	0	0	0	0	776
-PET. COKE	0	0	328	0	0	0	0	328
-NAPHTHA	0	0	0	0	0	0	0	0
-SPECIAL NAPHTHA	0	0	0	0	0	0	0	0
-ASPHALT & RD OIL	0	733	0	0	0	0	0	733
-LUBES & WAXES	0	0	133	0	145	0	0	279
-MISCELLANEOUS	0	0	0	0	0	0	0	0
-TOTAL PET. PRODUCTS	4095	733	3145	359	10456	563	86	19545
ELECTRICITY PURCHASED	1152	0	1159	0	16	0	239	2570
NUCLEAR & HYDROPOWER	0	0	0	0	0	1525	0	1525
TOTAL SECTOR (INCL. ELECT.)	10318	733	15440	730	10855	7797	1054	
LESS ELECT. GENERATED						2570		2570
TOTAL GROSS ENERGY	10318	733	15440	730	10855	5227	1054	44468

FIGURE A-2

YEAR...1985 TYPE OF ENERGY	RESIDENTIAL & COMMERCIAL N.F.	RESIDENTIAL & COMMERCIAL N.M.	INDUSTRIAL N.F.	INDUSTRIAL N.M.	TRANSPORTATION	POWER GENERATION	MISCELLANEOUS	TOTAL
					(TRILLION BTU'S)			
COAL								
-ANTHRACITE	0	0	0	0	0	0	327	327
-BITUMINOUS	609	0	5266	0	17	5485	0	11277
GAS								
-HEAT & POWER USE	5617	0	7049	0	517	2392	329	15906
-CARBON BLACK	0	0	0	119	0	0	0	119
-OTHER CHEM. FEEDSTOCK	0	0	0	196	0	0	0	196
PETROLEUM PRODUCTS								
-GASOLINE	0	0	0	0	9027	0	0	9027
-JET FUEL	0	0	0	0	1245	0	0	1245
-DISTILLATE	2772	0	600	0	1109	21	77	4583
-RESIDUAL	764	0	1098	0	740	722	62	3609
-KEROSINE	446	0	104	0	0	0	0	553
-LIQUID GASES	456	0	57	596	114	0	7	1232
-STILL GASES	0	0	811	53	0	0	0	865
-PET. COKE	0	0	443	0	0	0	0	443
-NAPHTHA	0	0	0	123	0	0	0	123
-SPECIAL NAPHTHA	0	0	0	156	0	0	0	156
-ASPHALT & RD OIL	0	889	0	0	0	0	0	889
-LUBES & WAXES	0	0	162	0	139	0	0	302
-MISCELLANEOUS	0	0	0	123	0	0	0	123
-TOTAL PET. PRODUCTS	4456	889	3275	1051	12374	743	146	23150
ELECTRICITY PURCHASED	1755	0	1478	0	15	0	345	3598
NUCLEAR & HYDROPOWER	0	0	0	0	0	2058	0	2058
TOTAL SECTOR (INCL. ELECT.)	12439	889	17068	1366	12923	10678	1147	
LESS ELECT. GENERATED						3598		3598
TOTAL GROSS ENERGY	12439	889	17068	1366	12923	7080	1147	52933

FIGURE A-3

YEAR...1970 TYPE OF ENERGY	HOUSEHOLD & COMMERCIAL N.P.	HOUSEHOLD & COMMERCIAL R.M.	INDUSTRIAL N.P.	INDUSTRIAL R.M.	TRANSPORTATION	POWER GENERATION	MISCELLANEOUS	TOTAL
					(TRILLION BTU'S)			
COAL								
-ANTHRACITE	0	0	0	0	0	0	209	209
-BITUMINOUS	323	0	4934	0	7	7207	0	12471
GAS								
-HEAT & POWER USE	7465	0	8899	0	745	4018	235	21366
-CARBON BLACK	0	0	0	88	0	0	0	88
-OTHER CHEM. FEEDSTOCK	0	0	0	597	0	0	0	597
PETROLEUM PRODUCTS								
-GASOLINE	0	0	0	0	11144	0	0	11144
-JET FUEL	0	0	0	0	2001	0	0	2001
-DISTILLATE	3059	0	605	0	1569	99	65	5401
-RESIDUAL	1172	0	1110	0	734	1991	45	5056
-KEROSINE	414	0	129	0	0	0	0	544
-LIQUID GASES	722	0	105	813	127	0	24	1794
-STILL GASES	0	0	983	75	0	0	0	1058
-PET. COKE	0	0	465	0	0	0	0	465
-NAPHTHA	0	0	0	300	0	0	0	300
-SPECIAL NAPHTHA	0	0	0	164	0	0	0	164
-ASPHALT & RD OIL	0	1081	0	0	0	0	0	1081
-LUBES & WAXES	0	0	164	0	137	0	0	321
-MISCELLANEOUS	0	0	0	172	0	0	0	172
-TOTAL PET. PRODUCTS	5367	1081	3581	1524	15712	2090	134	29501
ELECTRICITY PURCHASED	2776	0	1953	0	15	0	471	5218
NUCLEAR & HYDROPOWER	0	0	0	0	0	2811	0	2811
TOTAL SECTOR (INCL. ELECT.)	15931	1081	19367	2209	16479	16126	1049	
LESS ELECT. GENERATED						5218		5218
TOTAL GROSS ENERGY	15931	1081	19367	2209	16479	10908	1049	67043

TABLE A-4

1970 ENERGY CONSUMPTION INCLUDED IN
THE ENERGY CONSERVATION ANALYSIS

	FOSSIL FUEL (10^{12} BTU)	ELECTRIC (10^{12} BTU)	TOTAL (10^{12} BTU)
Residential/Commercial			
Included - residential	7,962	1,626	9,588
Included - commercial	3,301	1,150	4,451
Unaccounted for	1,892	0	1,892
Total[1]	13,155	2,776	15,931
Industrial[2]			
Included	20,012	1,953	21,965
Unaccounted for	692	0	692
Total[1]	20,704	1,953	22,657
Transportation			
Included	11,977	15	11,992
Unaccounted for	4,487	0	4,487
Total[1]	16,464	15	16,479
Electric Utilities			
Included	13,315	-	13,315
Unaccounted for	2,811[3]	-	2,811
Total[1]	16,126	-	16,126
Miscellaneous			
Unaccounted for[1]	578	471	1,049
Total			
Included	56,567	4,744	61,311[4]
Unaccounted for	10,460	471	10,931[4]
Total[1]	67,027	5,215	72,242[4]

[1] Source: MATHEMATICA Energy Data Base

[2] Includes ashphalt and road oil as raw material sector, which is included in the household/commercial sector in the data base.

[3] Nuclear and hydro power.

[4] This figure includes both the electricity consumed and the fossil fuels consumed to generate that electricity. The first column corresponds to the total energy consumed in the U.S. in 1970.

FIGURE A-5

BREAKDOWN OF RESIDENTIAL 1970 ENERGY CONSUMPTION

INCLUDED IN THE ENERGY CONSERVATION ANALYSIS

(10^{12} BTU)

USE	FOSSIL FUEL	ELECTRICITY	TOTAL
HOUSEHEATING	6375	629	7004
AIR CONDITIONING	3	460	463
REFRIGERATORS	0	810	810
FREEZERS	0	256	256
HOT WATER HEATERS	1206	763	1969
OVENS AND RANGES	312	338	650
OTHERS	66	1214	1280
TOTAL	7962	4470	12432

Source: See Chapter II

FIGURE A-6

BREAKDOWN OF THE 1970 COMMERCIAL ENERGY CONSUMPTION

INCLUDED IN THE ENERGY CONSERVATION ANALYSIS

CLASS	DESCRIPTION	Sq. Ft.[1] (MILLIONS)	ELECTRICITY		FOSSIL FUEL	
			KWH/SQ.FT.[2]	Billion KWH	Thousand BTU/Sq. Ft.[2]	TRILLION BTUs
1	RETAIL & OFFICE	7,590	20	150	150	1,138
2	RELIGIOUS	1,800	8	14	100	180
3	EDUCATIONAL	5,040	10	50	150	756
4	HOSPITALS	1,500	30	45	250	375
5	PUBLIC BUILDINGS	1,580	10	16	150	237
6	SOCIAL & OTHERS	4,100	15	62	150	615
TOTAL		21,610	-	337	-	3,301
EQUIVALENT TOTAL SOURCE ENERGY (trillions of BTU's)				3162[3]		3,301

A-8

1. Estimated from data in U. S. Dept. of Commerce, Construction Reviews and Statistical Abstract of the U.S.

2. Based on Spielvogel, L. Commercial Energy Conservation, Report Submitted to MATHEMATICA, Inc., August, 1974.

3. Electricity converted at 3412 BTU/KWH x 2.75

FIGURE A-7

BREAKDOWN OF THE 1970 INDUSTRIAL ENERGY COMSUMPTION[1]

INCLUDED IN THE ENERGY CONSERVATION ANALYSIS

	CONSUMPTION (10^{12} BTU)	PERCENT OF TOTAL
PROCESS STEAM	9,199	40.6
DIRECT HEAT	6,299	27.8
ELECTRIC DRIVE	4,350	19.2
ELECTROLYTIC PROCESS	634	2.8
FEED STOCK	1,994	8.8
OTHER	181	.8
TOTAL	22,657	100.0

[1]Electrical energy converted at 3,412 BTU/KWH.

Source: Estimated from data in Patterns of Energy Consumption in the U.S., Stanford REsearch Institute, 1972, and the MATHEMATICA Energy Data Base.

FIGURE A-9

BASELINE PROJECTIONS OF ENERGY CONSUMPTION
USED IN THE ENERGY CONSERVATION ANALYSIS

	1970	1977	1980	1985	1990
Residential/Commercial					
Included - residential	9,588	11,739	12,632	14,146	15,592
Included - commercial	4,451	6,592	7,510	9,249	10,990
Unaccounted for	1,892	2,341	2,572	2,988	3,395
Total	15,931	20,672	22,714	26,383	29,977
Industrial					
Included	21,965	29,045	30,900	33,683	47,328
Unaccounted for	692	915	973	1,061	1,491
Total	22,657	29,960	31,873	34,744	48,819
Transportation					
Included	11,992	14,703	15,847	18,600	22,587
Unaccounted for	4,487	5,502	5,930	6,960	8,452
Total	16,479	20,205	21,777	25,560	31,039
Electric Utilities					
Included	13,315	24,011	28,885	39,628	54,366
Unaccounted for	2,811	5,069	6,098	8,366	11,477
Total	16,126	29,080	34,983	47,994	65,843
Miscellaneous					
Unaccounted for	1,049	1,481	1,668	2,075	2,658
Total Energy Consumption					
Included	61,311	86,090	95,774	115,306	150,863
Unaccounted for	10,931	15,308	17,241	21,450	27,473
Total	72,242	101,398	113,015	136,756	178,336
Total Energy Input[1]	67,024	94,077	104,855	126,882	165,460

[1] Equal to total energy consumption minus electricity consumption.

FIGURE A-8

BREAKDOWN OF THE 1970 ENERGY CONSUMPTION BY THE TRANSPORTATION SECTOR INCLUDED IN THE ENERGY CONSERVATION ANALYSIS

TYPE	MODE		1970
Passenger	Automobile -		
		Intercity	5,695
		Other	3,235
		Total	8,930
	Railroad		32
	Bus		
		Inter City	40
		Intra City	45
	Airplane		1,251
	Total		10,298
Freight	Trucks and Rail		1,694
TOTAL			11,992

APPENDIX B

METHODOLOGY FOR ESTIMATING THE MAXIMUM ENERGY SAVINGS RESULTING FROM RESIDENTIAL ENERGY CONSERVATION MEASURES

MATHEMATICA

APPENDIX B

METHODOLOGY FOR ESTIMATING THE MAXIMUM ENERGY SAVINGS RESULTING FROM RESIDENTIAL ENERGY CONSERVATION MEASURES

Using the maximum per unit energy savings resulting from each of the conservation measures described in section the resultant energy savings for the entire U.S. were calculated for the years 1977, 1980, 1985, and 1990.

This was done as follows:

- project total number of housing units separately for single and multi-unit dwellings.
- project appliance saturations based on historical data.
- calculate number of appliances in use by multiplying the total number of housing units by each appliance's saturation.
- project per unit energy consumption based on historical trends and engineering considerations.
- calculate total energy consumed by the appliance by multiplying the number of units in use by the per unit energy consumption.
- determine that portion of the energy consumed by each appliance or use which can utilize each energy conservation measure. (These are given for each measure in Figures B-1&2).
- calculate the energy savings by multiplying the energy consumed which can take advantage of the energy conservation measure by the per cent energy savings. (The per cent energy savings are given in Figures B-1 & B-2).

This is expressed analytically as:

$$ES_{ijk} = HU_i\left(\frac{SAT_{ij}}{100}\right) UE_{ij} FR_{jk} \left(\frac{PES_{jk}}{100}\right)$$

where:

ES_{ijk} = energy savings in year i resulting from the implementation of strategy k associated with appliance j

HU_i = housing units in year

SAT_{ij} = per cent saturation of appliance j in year i

FIGURE B-1

UNIT PER CENT ENERGY SAVINGS

RESIDENTIAL SECTOR

FOR

ENERGY CONSERVATION MEASURES

MEASURE	POTENTIALLY APPLICABLE UNITS	PER CENT* UNIT SAVING	
R1 Increase efficiency of residential house-heating through cleaning and flue heat recovery.	All fossil fuel furnaces in new construction	15.0	
R2 Increase residential insulation		Heating	Cooling
1. Retrofit			
a) Attic Insulation	18 million existing 1 and 2 unit homes	7.9	10.3
b) Storm or Thermo-pane windows	20 million existing 1 and 2 unit homes	6.5	12
c) Weatherstripping	20 million existing 1 and 2 unit homes	5.0	1.2
2. New Construction			
a) 1 and 2 units	all new units	33.0	8.0
b) Multi-units	all new units	33.0	11.0
R3 Improved Efficiency of Appliances			
1. Hot Water Heaters	all new units	25.0	
2. Air Conditioners			
a) Cleaning	all new & existing units	5.0	
b) Improved room unit efficiency	all new units	40.0	
c) Improved central unit efficiency	all new units	15.0	
3. Refrigerators & freezers	all new units	56.0	
4. Stoves and Ovens	all new units	27.5	
R4 Thermostat Setting			
1. Heating	all units new & existing	9.4	
2. Cooling	all units new & existing	15.0	
R5 Use of Solar/Heat Pumps	See Figure II-15		

*These percentages are not additive.

FIGURE D-2

RATE OF IMPLEMENTATION OF SOLAR/HEAT PUMPS
AND CORRESPONDING ENERGY SAVINGS

	TYPE OF UNIT		
	Water Source Heat Pump	Solar Assist	All Solar
Energy Savings (% of heating load)	30	60	95
Applied to:	New electric dwellings	All new construction	All new construction
Fraction of units which can use device:			
1977	5	0	0
1980	10	3	0
1985	20	6	2
1990	35	10	5

Source: Estimates made in report by H. Brown of Drexel University to MATHEMATICA.

UE_{ij} = per unit energy usage of appliance j in year i

FR_{jk} = fraction of housing units which can utilize energy conservation measure k associated with appliance j

PES_{jk} = per cent energy savings resulting from the implementation of energy conservation measure k associated with appliance j.

1. PROJECTIONS OF HOUSING UNITS

Housing projections were based on a model which included the effects of housing abandonment and the decreasing ratio of people per housing unit. Housing abandonments deplete the total occupied housing stock at a rate of about one per cent per year. Thus, new construction must replace depleted housing as well as meet the housing demands of the population.

The second effect is a historical trend (Figure B-3) toward fewer occupants per dwelling unit. Because of this trend, additional demand for housing is created even in the absence of population growth. More housing units would be needed to allow more housing space per person.

The above effects differ in magnitude according to region. Therefore, projections of future U.S. housing stock were made at the regional level using regional population projections.[1] The model was applied using 1972 as the base year.[2]

The model employed projected population trends, depletion rates, and people per dwelling unit ratios to arrive at total housing stock and new construction as follows:

$$HU_T = POP_T / PH_T$$

and

$$NH_T = HU_T - HU_{T-1} + REP_T \times HU_{T-1}$$

where

HU_T = total occupied housing stock in year T

POP_T = population in year T

PH_T = people per housing unit in year T

1. Census projection I-E.

2. Details of this regional model are given in the documentation of the INTERMATICA Regional Housing Projection Model.

FIGURE B-3

HISTORICAL DATA ON POPULATION AND HOUSING

YEAR	RESIDENT[1] POPULATION (millions)	OCCUPIED HOUSING UNITS[1] (millions)	PEOPLE PER HOUSING UNIT
1950	151.3	42.8	3.53
1955	165.1	47.9	3.45
1960	179.3	53.0	3.38
1965	193.5	58.2	3.32
1970	203.2	63.4	3.21

[1]Bureau of Census.

REP_T = fraction of total occupied housing stock depleted during year T

NH_T = new housing constructed in year T

The model was also used to forecast the number of singly occupied dwellings. To accomplish this, the percentage of new single unit construction of the total new constructions was estimated for the year 1971, 54%[1], and assumed to be constant throughout the span of the projections. Using a base single dwelling unit housing stock of 47.1 million units for 1972, knowing additional new single unit construction would subsequently give the future single unit housing stock if the depletion effect is taken into account. Thus,

$$SHU_T = f_1 \times SHU_{T-1} + NSC_T$$

where

SHU_T = total single unit housing stock in the year T

NSC_T = new single dwelling units constructed during the year T (which is assumed to be a fixed fraction of total new construction).

f_1 = the depletion factor for housing units removed from the total stock.

To simplify the analysis, the projected size of the multifamily housing stock was assumed to be the difference between the total housing stock and the single unit housing stock. (The multi-family housing stock, therefore, includes mobile homes).

Projected housing stock values are shown in Figure B-4.

2. PROJECTIONS OF APPLIANCE SATURATIONS

The energy consuming units projected in this analysis were:

- home heating systems
- air contitioners
- water heaters
- freezers
- refrigerators
- ovens

---

[1] HUD, 1972.

FIGURE B-4

TOTAL HOUSING STOCK

(millions of units)

YEAR	TOTAL*	SINGLE	MULTI*
1970	63.417[1]	44.035[1]	19.382[1]
1976	69.973	49.467	20.506
1977	71.131	50.073	21.058
1980	74.682	51.943	22.739
1985	80.868	55.237	25.631
1990	87.423	58.770	28.653

1. Census of Housing, 1970.

   Projection: Based on trends in people per housing unit and new construction trends (See text).

*includes mobile homes.

The number of each of these appliances was linked to the number of homes in the United States. Projections of appliance saturations, or the percentage of homes with the given appliance, were made based on projections of past trends. These are shown graphically in Figures B-5 and B-6. By multiplying these saturations by the number of homes, the number of units in use in future years were calculated. (Figure B-7)

The projections of the saturation of room and central air contitioners were based on an exponential trend fit of the historical data. This was done because it was felt the recent rapid increases in the use of air conditioning would level off.

3. PER UNIT ENERGY CONSUMPTION

Projections of per unit energy consumption are based on extrapolations of recent trends (Figures B-8 and 9). The results are shown in Figure B-10. Projections of per unit usage of freezers and refrigerators were limited by the current units with the greatest consumption rate, namely frostfree refrigerators. This was done because recent rapid increases in energy consumption were due to entry of these units into the market. A simple extrapolation would result in per unit usages greater than the maximum per unit uage in existence today.

The househeating per unit usage trend was lowered because it is expected that trends to smaller homes and population shifts to milder climates will reduce the current upward trends.

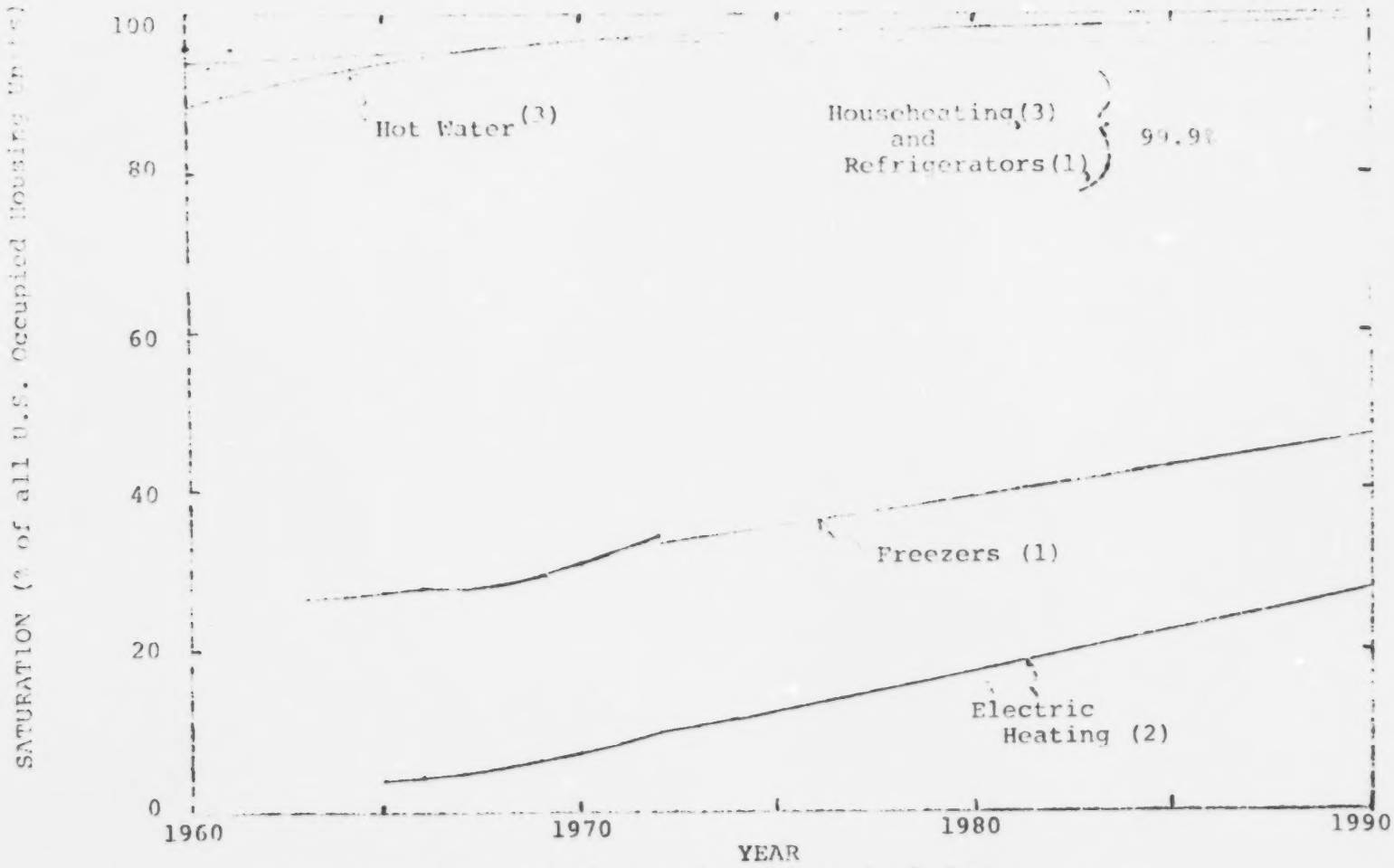
The total energy consumption is then the number of units multiplied by average usage (Figure B-11).

4. ENERGY SAVINGS

The energy savings were calculated by applying the percentage savings described in the previous section to the total usage of those units which could utilize the energy conservation measure. The number of units which could utilized the energy conservation measures

FIGURE B-5

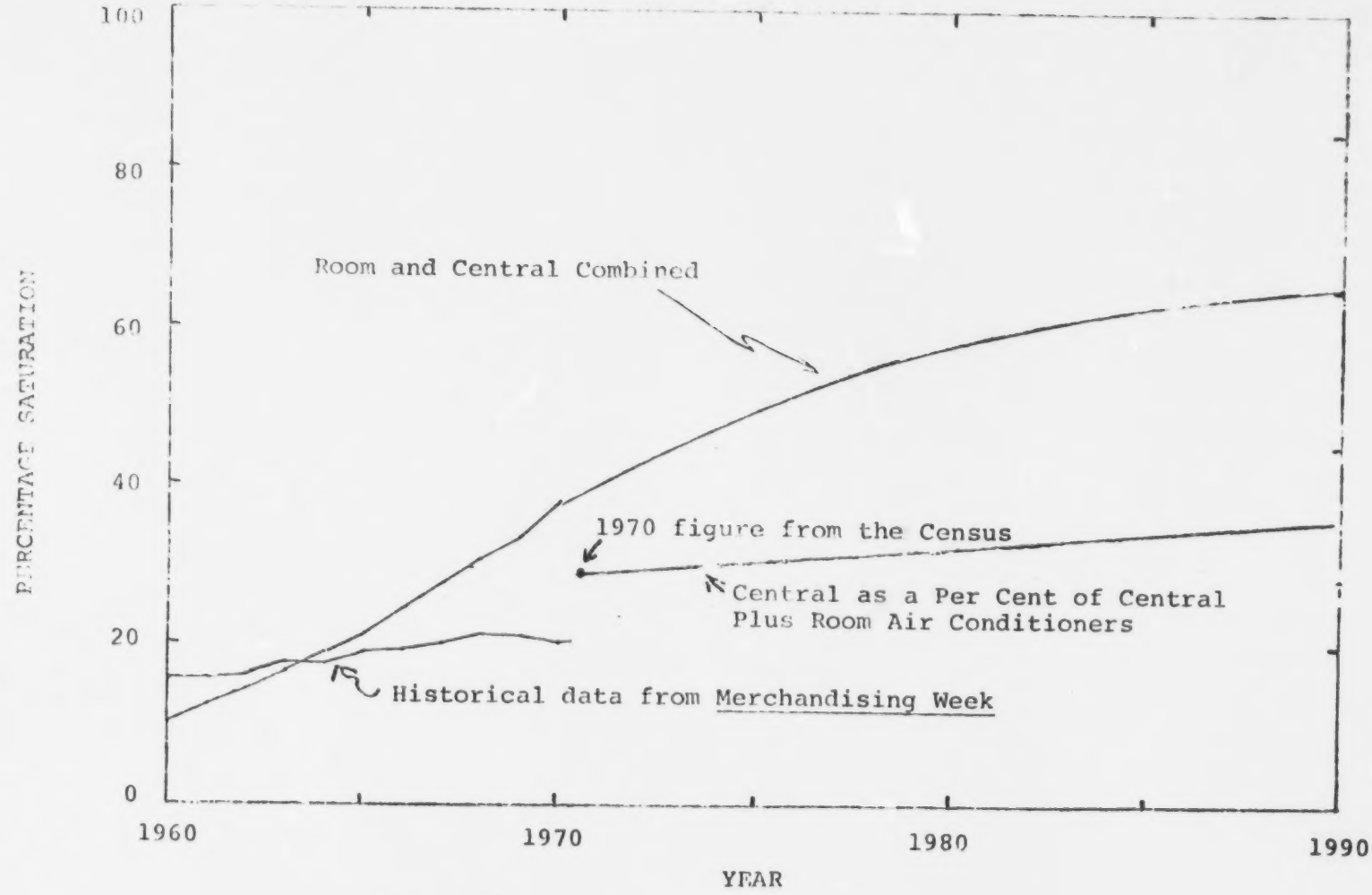
PROJECTIONS OF APPLIANCE SATURATIONS



Sources: Projections are trends based on historical data.
(1) Merchandising Week, 1974 Statistical and Marketing Report.
(2) Edison Electric Institute, Annual Housheating Survey (1966-1972).
(3) Census of Housing, 1960 and 1970, Bureau of the Census.

FIGURE B-6

PROJECTIONS OF AIR CONDITIONER SATURATIONS



Source: 1970 value is derived from the 1970 Census of Housing and the projections are based on trends reflected in Merchandising Week, 1974 Statistical and Marketing Report.

FIGURE B-7

PROJECTIONS OF STOCKS OF MAJOR APPLIANCES

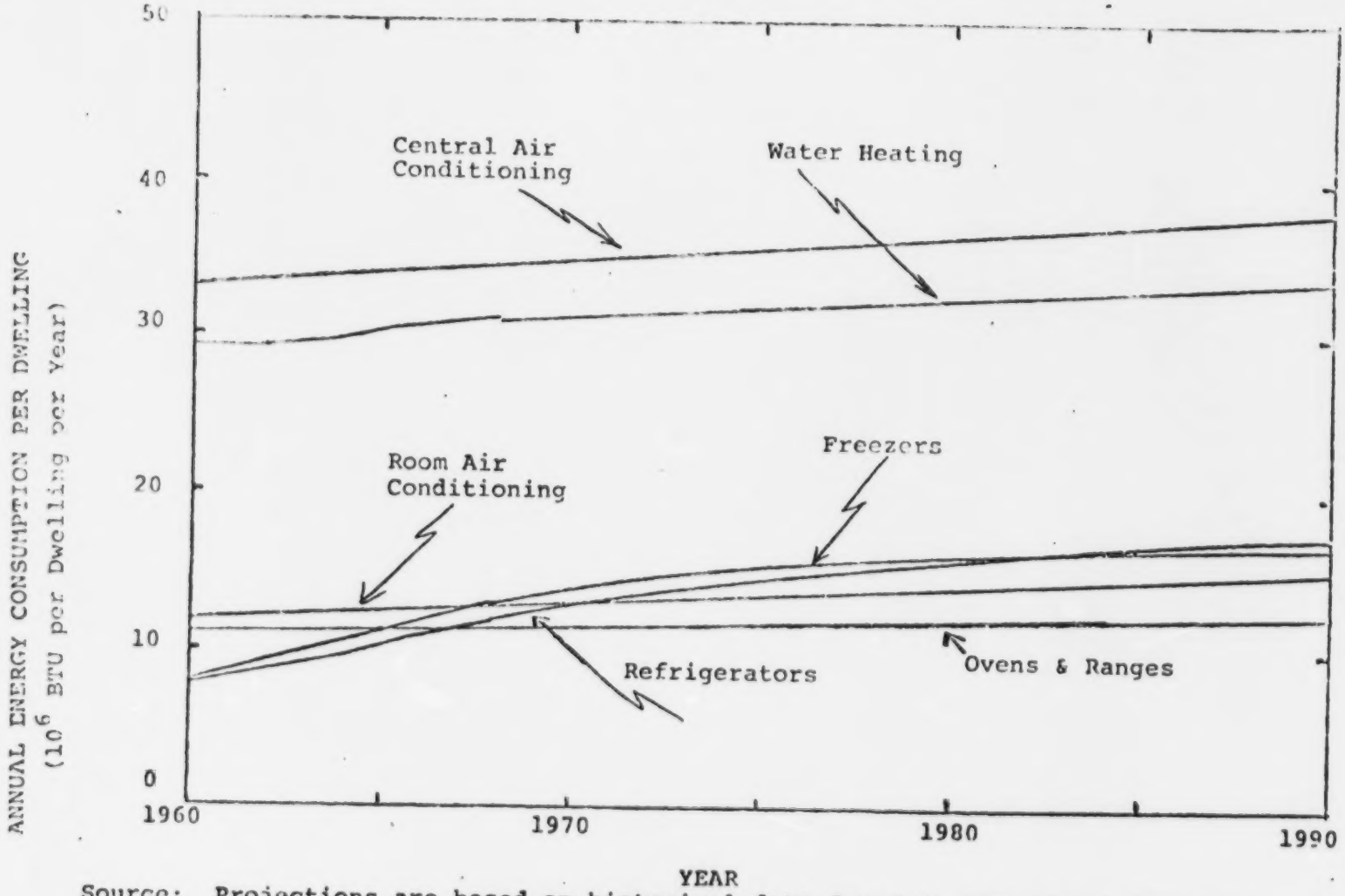
(Millions of occupied units having each appliance)

APPLIANCE	1970	1977	1980	1985	1990
HOUSEHEATING					
Single homes	43.8	49.8	51.9	55.2	58.9
Apartments	19.3	21.3	22.7	25.6	28.5
TOTAL	63.1	71.1	74.6	80.8	87.4
AIR CONDITIONING					
Central					
Single Homes	5.0	7.8	9.6	13.1	16.6
Apartments	1.8	2.8	3.4	4.7	5.9
TOTAL	6.8	10.6	13.0	17.8	22.5
Room					
Single Homes	11.4	17.8	19.4	21.8	22.9
Apartments	5.9	9.2	10.1	11.2	11.8
TOTAL	17.3	27.0	29.5	33.0	34.7
TOTAL AIR COND.	24.1	37.6	42.5	50.8	57.2
REFRIGERATORS	63.3	71.1	74.6	80.8	87.3
FREEZERS	19.7	26.3	29.3	34.8	40.8
HOT WATER HEATERS	63.3	69.5	73.2	79.7	86.5
OVENS & RANGES	60.2	67.5	71.0	76.9	83.0

Methodology: Multiply projections of housing stock (Figure II-17) by the respective saturation levels (Figures II-18 and II-19).

FIGURE B-8

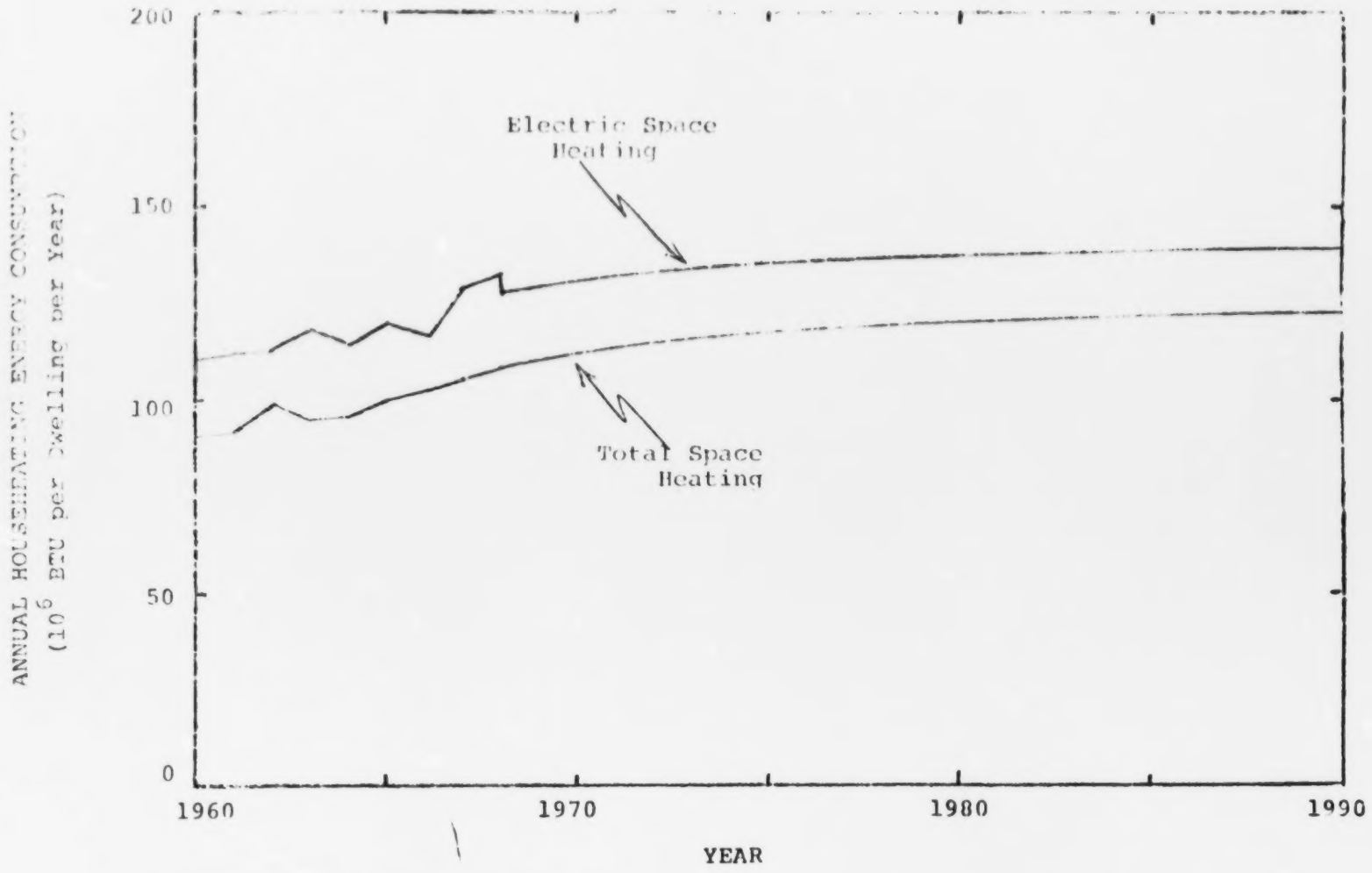
ANNUAL APPLIANCE ENERGY CONSUMPTION PER DWELLING UNIT



Source: Projections are based on historical data found in SRI report "Patterns of Energy Consumption in the U.S.," January 1972, NTIS EP-212-776.

FIGURE B-9

ANNUAL HOUSEHEATING ENERGY CONSUMED PER DWELLING UNIT



Source: Projections are based on historical data found in SRI Report "Patterns of Energy Consumption in the U.S.", January 1972, NTIS BP-212-776.

FIGURE B-10

AVERAGE ANNUAL HOUSEHOLD ENERGY CONSUMPTION BY USE

(10^6 BTU of Fossil Fuel Energy)

APPLIANCE	1970	1977	1980	1985	1990
Househeating					
Total	111.	118.	120.	133.	123.
Electric	131.	137.	138.	139.	139.
Air Conditioning					
Room	13.1	13.1	13.1	13.1	13.1
Central	34.8	34.8	34.8	34.8	34.8
Refrigerators	11.93	14.9	15.6	16.8	17.3
Freezers	12.9	15.6	15.9	16.3	16.5
Hot Water Heaters	31.2	32.0	32.4	33.1	33.7
Cooking	10.9	10.8	10.8	10.8	10.8

Source : MATHEMATICA estimates based on trended projections from "Patterns of Energy Consumption in the U.S.", Stanford Research Institute.

FIGURE B-11

RESIDENTIAL ESSENTIAL ENERGY DEMAND* BY USE

(10^{12} BTU)

APPLIANCE	1970	1977	1980	1985	1990
HOUSEHEATING					
Single	5463	6611	7000	7610	8172
Multi	1541	1779	1952	2248	2566
TOTAL	7004	8390	8952	9858	10738
AIR CONDITIONING					
Central					
Single	174	271	334	456	578
Multi	63	94	118	163	205
TOTAL	237	365	452	619	783
Room					
Single	149	233	254	286	300
Multi	77	120	132	147	155
TOTAL	226	353	386	433	455
TOTAL AIR COND.	463	718	838	1052	1238
REFRIGERATORS	810	1059	1164	1357	1510
FREEZERS	256	410	466	567	673
HOT WATER HEATERS	1969	2224	2372	2638	2915
OVENS & RANGES	650	729	767	831	896
OTHER**	1280	1553	1671	1872	2063
TOTAL	12433	15083	16230	18175	20033

*Primary fossil fuel equivalent input to all power generating facilities.

**Estimated at 10.3% of total residential energy demand.

Methodology: Multiply per unit usage of energy (Figure II-23) by number of units (Figure II-20).

were expressed in four ways: (1) all future new units as of a given year; (2) all existing units as of a given date; (3) all units, both existing and new; and (4) a given number of units.

The projections of future new units beyond a given year were made by assuming a retirement rate on the units in existence in that year. The retirements per year expressed as a per cent of the total number of units in use are as follows:

- Houses 1.0%
- Househeating units 5.0%
- Hot water heaters 10.0%
- Air conditioners 10.0%
- Refrigerators 6.7%
- Freezers 6.7%
- Oven and ranges 6 7%

(In the case of heat pumps, which are applied to newly constructed electric homes, it was assumed that no electrically heated homes were abandoned).

The number of units in any future year represented by new production since the base year was then determined by subtracting from the projections of total appliances in the future year the decreased number of units that were in existence in the base year. This is expressed analytically as:

$$NP_{ijk} = EU_{ik} - EU_{jk}\left(\frac{RR_k}{100}\right)^{i-j+1}$$

where

NP_{ijk} = new production of appliance k from base year i to year j

EU_{ik} = existing units of appliance k in year i

RR_k = yearly retirements as a per cent of existing units.

The resultant energy savings are given in Figure B-12.

FIGURE B-12

POTENTIAL ENERGY SAVINGS RESULTING FROM PROPOSED ENERGY CONSERVATION MEASURES

(10^{12} BTU of FOSSIL FUELS)

STRATEGY	1977	1980	1985	1990
R1 Increase the efficiency of residential househeating units through flue heat recovery	113	275	463	631
R2 Increase residential housing insulation:				
1. Retrofit				
a) Attic Insulation-heating	184	179	170	162
-cooling	18	17	16	16
b) Storm or Thermopane Windows -heating	170	165	156	148
-cooling	23	22	21	20
c) Weatherstripping-heating	131	127	120	114
-cooling	2	2	2	2
Total	528	512	485	462
2. New Construction				
a) 1 & 2 units -heating	86	277	578	858
-cooling	3	11	24	37
b) Multi-units -heating	33	107	231	361
-cooling	3	7	15	21
Total	125	402	848	1277
R3 Improve Appliance Efficiency				
1. Hot Water Heaters				
New Construction	116	272	470	617
2. Air Conditioners				
a) Clean, all units	36	42	53	62
b) Improve efficiency of room air conditioners	33	76	127	154
c) Improve efficiency of central air conditioners	13	37	75	107
Total	82	155	255	323
3. Refrigerators	95	247	484	643
4. Freezers	135	353	692	943
5. Ovens & Ranges	29	71	130	177
R4 Thermostat Setting				
1. Heating	787	841	921	1009
2. Cooling	108	126	158	186
R5 Solar/Heat Pumps	12	56	256	683

All strategies are assumed to be implemented in 1976.

Strategies are not necessarily additive.

APPENDIX C

SERIES SYSTEMS UTILIZING DOMESTIC HOT WATER FOR SPACE HEATING

MATHEMATICA

APPENDIX C

SERIES SYSTEMS UTILIZING DOMESTIC HOT WATER FOR SPACE HEATING

J.R. PIPER
Member ASHRAE

This paper is based on the experience gained from the design and installation of series-loop hydronic systems, utilizing domestic hot water for space heating, in approximately 4000 apartment units since June of 1968. Additional information has been supplied from a system installed in the author's home which has been in operation since September of 1967.

Traditionally, hydronic heating systems have been classified as *two pipe, one pipe,* and *series systems.* The last of these, series systems, have generally been designed as baseboard systems for a few number of heat exchangers, and a short length of main piping. They have suffered from difficulty of individual control at the heat exchanger and been confined to small loops or small parts of larger parallel systems

The system described herein is an approach to the use of series hydronics system not heretofore published. The size of the system is not limited (within reason) with the arrangement described actually gaining advantages, due to redundancy and diversity, as the loop grows longer.

It has long been recognized that series systems were inherently the lowest priced hydronic systems due to the relatively small amount of material required to assemble one. But now, by designing a series hydronic space heating system so that it is also the hot tap water distribution system, it is possible to assemble a system from high quality components and material, which will compete with any conventional form of heating and water heating on a first cost basis, and show dramatic cost savings in operation.

DESIGN CONSTRAINTS

As in any series system, there are certain basic design constraints that must be dealt with. The most serious of these is the progressive temperature drop of the water as it passes through each heat exchanger, since the ΔT depends on the mass flow through, and the amount of heat removed from, the exchanger. A system loop could theoretically be designed with an almost infinite length if the mass flow was almost infinite. This would require a rather large piping main (almost infinite in diameter) which would cost an almost infinite amount of money. This particular limitation has been a difficult one to overcome (that is, piping main size/cost regarding mass flow).

Hydronic manuals generally describe series systems as limited to "complete small systems," or "for terminal or branch circuits on large systems." When designed as "part of" a larger system, the series section is then placed in parallel with other sections which cause it to have imposed on it the design constraints of parallel systems (control valves, balancing, etc.), and consequently, many advantages of the pure series system are lost.

SERIES LOOP APPLICATION

Our approach will not require large diameter main piping for a long series loop. There is, for example, one series loop (similar to the one described here) with 18,000 ft of 1½ in. Type "M" copper piping, serving 508 apartments for space heating and domestic hot water, in Costa Mesa, Calif. The principle used in its design is identical to our example (Fig. 1) of a 54 unit apartment complex in Fullerton, Calif. The plan view of this installation appears in Fig. 1. This is an actual installation and has been operating since September of 1969. The building is two story, contains 54 units, a recreation room, and self service laundry. There are approximately 1500 ft of 1½ in. Type "M" copper piping in the main loop. There are 58 heat exchangers in the complex. Fifty-two apartments contain one exchanger each; two apartments contain two exchangers, the recreation room contains one exchanger; and the swimming pool is heated with an exchanger (shell and tube). There are five heat sources capable of adding heat to the loop. Since it is possible to remove heat from the loop by utilizing heat exchangers in series, it is possible to add heat the same way. Fig. 1 shows low temperature boilers (the heat source) in series with the loop. These are gas fired, copper water tube, direct heating boilers. They are distributed along the length of the loop in a manner so as to place a relatively equal load on each. Except for the pool exhanger, the heat exchangers in the loop between the boilers are water to air, which we will refer to as "coils." The length of the loop between boilers we will refer to as "segments." Each of these segments may be examined independently to calculate

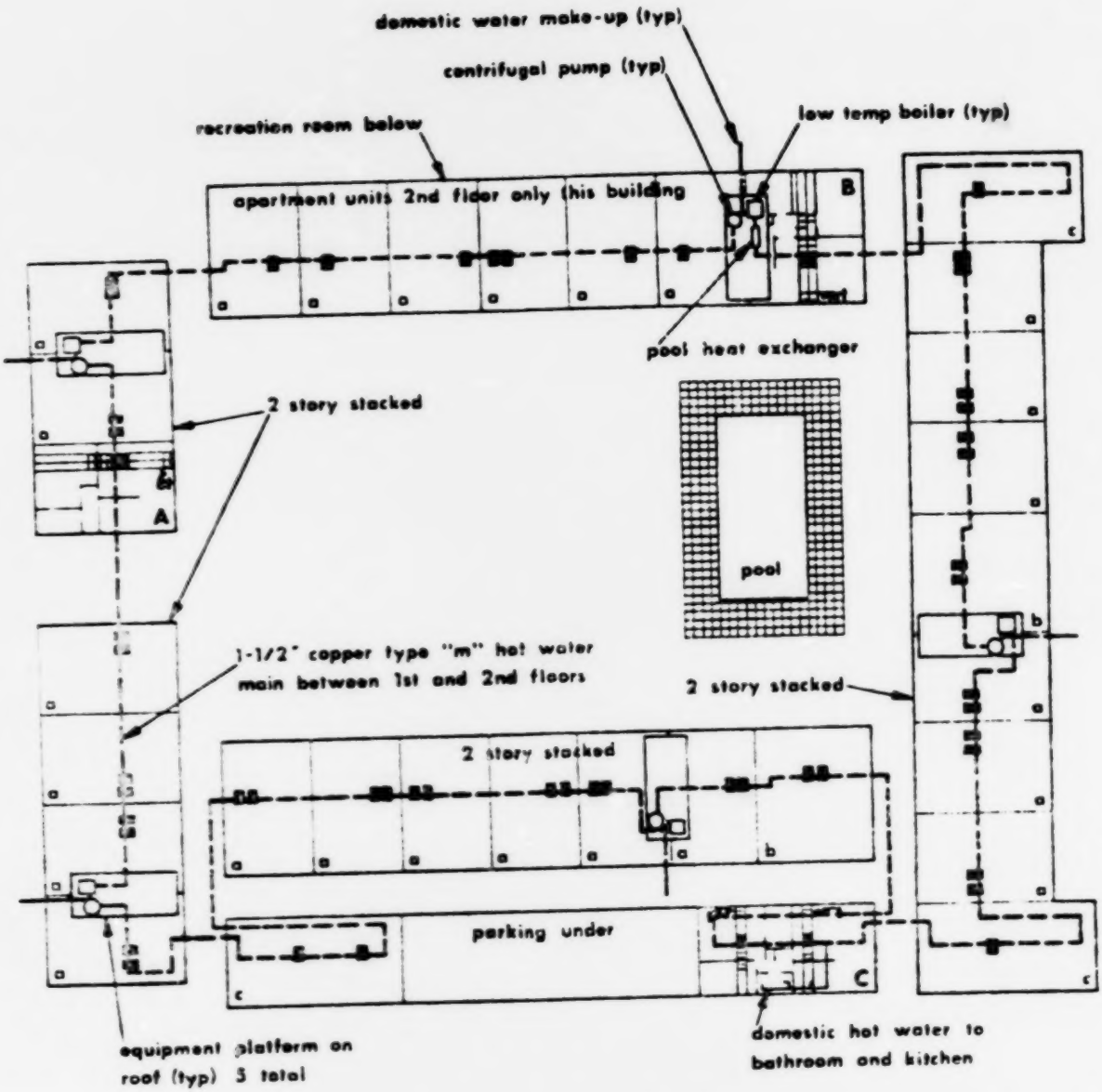


DIAGRAM OF SERIES LOOP SYSTEM

54 apartment units in Fullerton, California

Fig. 1 Diagram of series loop system

Reproduced from best available copy.

1. The maximum heat demand per segment DMs
2. The maximum temperature drop per segment ΔTs
3. The average temperature drop per coil ΔTe

ΔTe is of some considerable interest since it is very small when compared to that encountered in a parallel system utilizing standard fan coils.

In this case

Heat loss calculations for a typical apartment unit indicated a 99% day would require 15,000 Btuh. The median zone was designed with an air flow over the coil which produces 17,000 Btuh. The water flow rate was picked as 30 gpm

ω = 8.33 lbs/gal x 30 gpm x 60 min =
Approximately 15,000 lbs/hr
DMs = 11 hrs x 17,000 Btuh = 187,000 Btuh max.
ΔTs = 187,000/15,000 = 12.5 F
ΔTe = 12.5 F/11 = 1.135 F

The second most limiting factor in series systems is control of the heat flow out of the coil. In this system, since radiation from the coil is negligible with the water temperature used, this is accomplished with the air flow over the coil. A thermostat, sensing room temperature, operates a blower that produces a forced draft through the coil. When the blower is off, and there is no forced draft over the coil, the components are arranged to prohibit convective flow. It becomes apparent then that maximum demand on the system occurs only when the duty cycle of the blowers reaches unity. Any other demand is *less* than maximum demand, and it is this situation that obviously predominates.

The capacity of the last coil in a segment during this later condition becomes operationally indistinguishable from the first, with any "capacity differential" being automatically adjusted by the duty period of the blower in the last zone lengthening, and the first zone shortening.

DOMESTIC HOT WATER INTEGRATED

The series system described so far could be used for space heating without integrating it with the domestic hot water system. The design constraints imposed by adding the domestic water system will now be examined.

In Fig. 1 it will be seen that there is a domestic cold

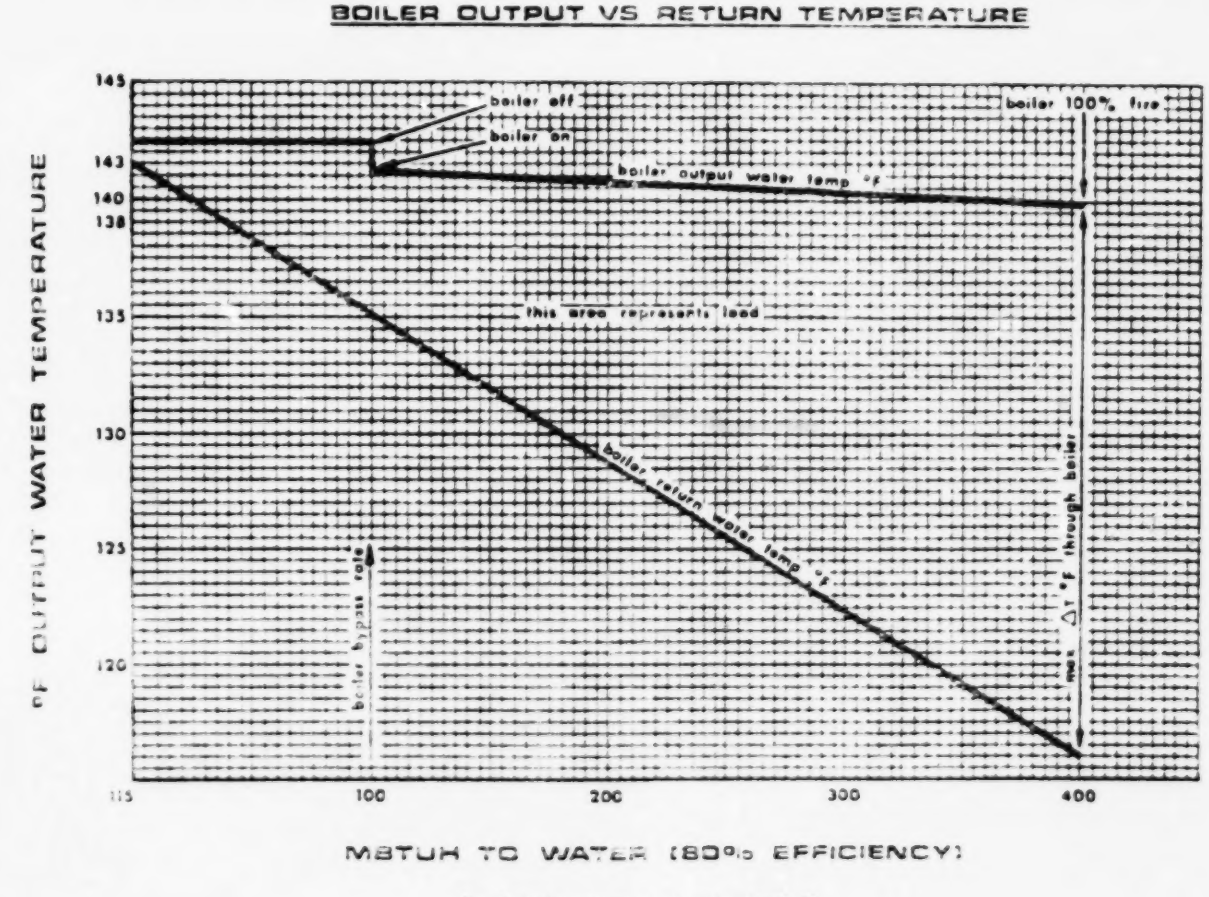


Fig. 2. Boiler output vs. return temperature

water make up entering the system between the circulating pump and the boiler on each equipment platform. There are reducing T's in the loop between platforms that allow 3/4 in. copper deadmen to be run from the loop main to the fixtures within the apartments. The water pressure within the loop leaving each platform, is the static pressure within the cold water make-up, plus the pump head caused by resistance to the circulating flow. This remains constant (since the pumps run continuously) until a tap is opened drawing hot water from the system. At that instant there is a pressure drop within the system which causes a flow of cold make up water to enter the loop just before the boiler, and mix with the circulating water. Before this instant, with no space heating demand, or domestic tap water loss, there was no demand for energy input at the boiler (ignoring line heat losses), and therefore the boiler water output temperature was nominally 143 F. After this instant, with some cold water entering the loop (perhaps 5 gpm) and mixing with the circulating flow (30 gpm) the boiler water temperature was lowered.

Should there have been a demand for space heating in the segment before the boiler, the boiler water temperature would have been lowered even more.

Both the cold make-up water and the space heating demand are "load" for the boiler, and may occur independently or together.

ENERGY CONTROL

To maintain the domestic tap water temperature within acceptable limits, the boiler controls have been arranged so that they function as a servo. This control system modulates energy (gas) input to the boiler as a function of the boiler water output temperature.

The control has approximately a 5 deg operating modulation differential, ΔM, which is proportional to energy demand in the following manner:

138 F	=	100% demand
143 F	=	20% demand = bypass rate
143 F+	=	off

In operation, when the boiler is off, the control senses a temperature drop and "lights off" the boiler at the bypass rate. Since the boiler water output temperature is directly proportional to system load, as the temperature of the boiler output water decreases, the energy input increases, until at 138 F the full rated energy input of the boiler is achieved. Should a greater than design load be imposed on the boiler momentarily, the water temperature will decrease to a temperature below 138 F until that load is reduced.

Fig. 2 graphically shows boiler water output temperature plotted vs boiler input. Boiler return (or input) water temperature is plotted for the boiler capacity used on the system in Fig. 1. The modulation function was assumed as a straight line with no hysteresis.

It should be stressed that the bypass rate of the boiler must be lower than the *minimum* load placed on the system by one shower drawing hot tap water, plus line loss. Ignoring this constraint will cause short cycling of the boiler and resultant "slugs" of hot and cold water circulating through the loop. It has been demonstrated that without modulation, where the boiler operates with a bang-bang control function, it is possible to obtain 55 F swings in water temperature with an on-off control set for 5 F.

DISTRIBUTION PIPING

One of the most important design constraints imposed on the system is the diameter of the distribution main. The domestic water distribution requirements now govern, and the calculations required to satisfy code conditions (8 psi at the last fixture) become complex. This is due to the diversity of the "single size main" loop, the circulating flow rate, the multi-input cold water make ups, and the difficulty in sometimes finding the "last" fixture.

Examining this area is beyond the scope of this paper, but suffice it to say that 1½ in. copper tubing has become standard as the main size in all system designs at present.

ECONOMICS

The economics of this system have been left for last, and rather than use numbers that may change from one geographical area to another, the basis for the costs will be examined.

Three separate areas contribute to the building system cost which must be charged to domestic water heating or space heating. These are cost of equipment and installation (boilers, pumps, coils, etc.), cost of material and installation (piping, fittings, wiring, etc.), and cost of building construction provided for the space heating-water heating system. The total cost for these three areas can only be determined by compiling a weighted "spread sheet," similar to the one prepared by the builder for total construction cost breakdown. When this is prepared, the cost of the space heating-water heating portion of the building system shows up as a bottom of the balance sheet figure, which is the *real* comparative cost as far as the builder is concerned. Table I contains a list of items in such a breakdown, which show comparisons between common systems used in wood frame construction in the Western United States.

It may be noted that the cost of domestic hot tap water distribution main may be lower with this system than it would be with a standard recirculating system. Since this does not take into account the space heating function at all, when that function is also served by the *same* piping, a tremendous economic advantage is immediately gained.

It also becomes obvious that there are a relatively small number of moving parts associated with such a combined system. They are essentially limited to boiler controls, and the pumps, on the equipment platforms, and to thermostats and the blower motor in the apartments.

This feature provides a definite tendency towards low maintenance costs, since there just aren't many moving parts to fail.

The efficiency of the system is very high, also. Since there is relatively very little unwanted heat transfer out of

the system with the 140 F water temperatures and the majority of the main piping in dead air spaces, and since the copper water tube boiler is a rather efficient device, the project operator has an opportunity to buy delivered energy at a very low cost.

Other advantages to the system are:

1. Very little potable water waste while waiting for the cold water to drain from the hot water line.
2. No dust carbonization in the air passing through the coil (no black streaks at the register).
3. No fire hazard at the zone (due to 140 F water).
4. Individual zone control.
5. Unlimited domestic hot tap water (customer never "runs out").
6. No special clearances from combustible building components (due to 140 F water).
7. Long life components.
8. Instant space heating always available.

BIBLIOGRAPHY

1. ASHRAE GUIDE AND DATA Book, Systems and Equipment 1967 Chapters 54 and 55.
2. Uniform Mechanical Code 1970.
3. Uniform Plumbing Code 1967.
4. City of Los Angeles Plumbing Code 1968 edition.
5. City of Los Angeles Heating, Ventilating, and Air Conditioning Code 1970 edition.
6. Cameron Hydraulic Data 1965 edition.

TABLE I

The items on this page should be costed for labor and material for each system considered. These generally apply for wood frame apartment construction in the far western part of the United States. Other geographical areas, with other types of construction, require comparable cost headings for that type of construction.

Electrical:
- Building Subfeeds
- Range Drop
- Boiler Control Connect
- Pump Connect
- Panels & Breakers
- Blowers Connect
- Thermostats Connect
- F.A.U. Connect
- Ceil Heat & Drop
- Heat Strip & Drop

Heating:
- Sheetmetal
  - Combustion Air
  - Vents
  - Ducts
- Furnace
- Boiler
- Blower, Coils, Registers
- Thermostat

Plumbing:
- Hot Water Main
- Gas Range Stub
- Forced Air Stub
- Yard Pipe Gas
- Boiler Stub
- Set Equipment
- Install Coils
- Trench, Backfill
- Tank Type W.H.

Construction:
- Lost Space
- Furring
- F.A.U. Closet
- Platforms
- Boiler Rooms
- Insulation
- Ceil Heat Drywall

APPENDIX D

DERIVATION OF CARPOOL MODEL

MATHEMATICA

APPENDIX D

DERIVATION OF CARPOOL MODEL

Given the above assumptions, if we let:

PM_O = passenger miles at current occupancy rates

VM_O = vehicle miles at current occupancy rates

X_O = current occupancy rate per vehicle mile = 1.63

PM_C = changed passenger miles after carpooling

VM_C = changed vehicle miles after carpooling

X_C = changed occupancy per vehicle mile

Γ = average rate of energy consumption for home-to-work trips in miles per gallon

The following relationships should hold.

F_O = fuel consumption before carpooling = $\frac{VM_O}{\Gamma}$

F_C = fuel consumption after carpooling = $\frac{VM_C}{\Gamma}$

The occupancy rate per vehicle mile is defined as the ratio of passenger miles to vehicle miles, so:

(1.) $X_O = \frac{PM_O}{VM_O}$ and $X_C = \frac{PM_C}{VM_C}$

Thus:

(2.) $VM_O = \frac{PM_O}{X_O}$ and $VM_C = \frac{PM_C}{X_C}$

Because of the assumed 5% extra passenger miles per rider:

(3.) $PM_C = PM_O\ (1 + .05\ (X_C - X_O))$

Using these relationships, the fuel consumption before and after carpooling becomes:

(4.) $F_o = \frac{PM_o}{\Gamma X_o}$ and $F_c = \frac{PM_o\ (1+\ .05\ (X_c - X_o))}{\Gamma X_c}$

The fractional amount of energy saved, f, is:

(5.) $f = \frac{F_o - F_c}{F_o}$

Substituting the relationships (4) into (5) we obtain:

$$f = \frac{\frac{PM}{\Gamma X_o} - \frac{PM}{\Gamma X_c}\ (1+\ .05\ (X_c - X_o))}{\frac{PM}{\Gamma X_o}}$$

This reduces to:

$$f = 1 - \frac{X_o}{X_c}\ (1 + .05\ (X_c - X_o))$$

APPENDIX E

CALCULATION OF AUTO FUEL CONSUMPTION

MATHEMATICA

APPENDIX E

CALCULATION OF AUTO FUEL CONSUMPTION

Fuel consumption in a given calendar year is calculated as the sum of contributions from different model years. The total number of vehicle miles driven by cars from a contributory model year is divided by the historical or projected miles per gallon for that model year. This represents an estimate of model year fuel consumption which is then added to others to form the estimate of calendar year fuel consumption.

Total vehicle miles for a model year is determined as the product of vehicle miles driven by cars in the model year times the number of cars from the model year which are still in operation. The average number of vehicle miles per car in a calendar year is the total forecast vehicle miles for that year divided by the total forecast vehicles. For a model year this average must be modified because cars are driven less as they grow older. The FHWA Nationwide Personal Transportation Study determined the relative amounts cars of different ages were driven in 1969. These relative amounts are assumed in this study to remain constant.

A factor was calculated as the average miles driven for a given vehicle age divided by the average for all cars. This factor is plotted in Figure E-1 as the "Raw Factor". Since there was variability due to the relatively small sample size for older model years, a 3 point moving average (MA) of the raw factor was actually used. This is also plotted in Figure E-1. By multiplying this factor times the overall average vehicle miles driven, the model year average vehicle miles was computed.

The total vehicles remaining in a calendar year was determined by the use of scrappage curves, such as that shown in Figure E-2. These curves are based on those used in the Chase Econometrics

Study for CEQ on Forecasting Automobile Fuel Consumption. A continued slight tendency towards cars being scrapped earlier is forecast. Figures E-3a, b, c and d show original registrations, number remaining average vehicles miles and total vehicle miles for each model year in 1977, 1980, 1985 and 1990 respectively.

The miles per gallon in the base is shown in Figure E-3. These are the values determined in the Chase study. These figures show projected increase in fuel efficiency based upon an assumed increasing mix of smaller cars. Fuel use by model year is also shown in Figure E-3.

Conservation of total fuel consumption has two components. For autos from model years prior to 1976, only engine tuneups are assumed to be applied for a 5% savings. For 1976 and later model years, four measures are applied:

1. Tune Ups
2. Aerodynamic Design
3. Continuously Variable Transmission
4. Radial Tires.

It is assumed that these measures are applied to all autos, raising their fuel consumption rates to 20 mpg. Figure E-4 shows the savings resulting in these two areas.

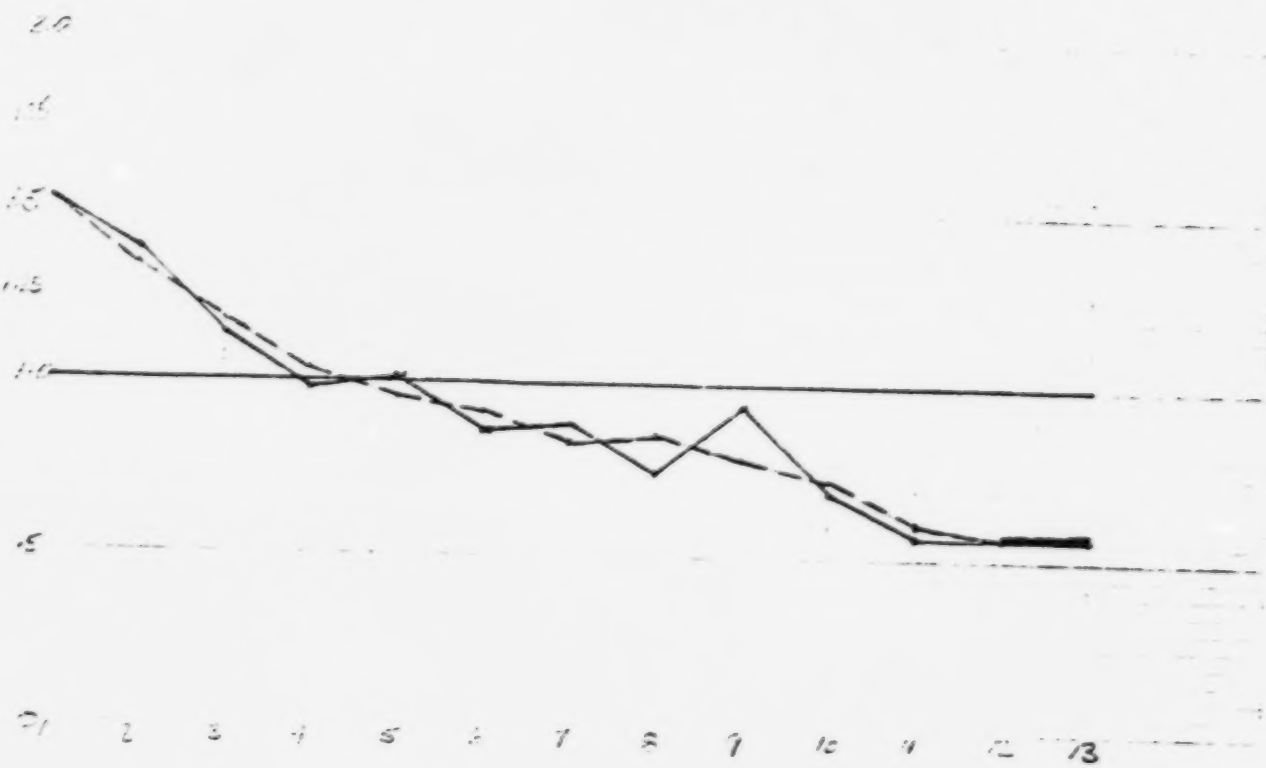
FIGURE E-1

AVERAGE MILEAGE FACTOR

Reproduced from best available copy.

M.L. FACTOR ——

RAW FACTOR ——



AGE OF VEHICLE

Reproduced from
best available copy.

FIGURE E-2

TYPICAL SCRAPEAGE CURVE

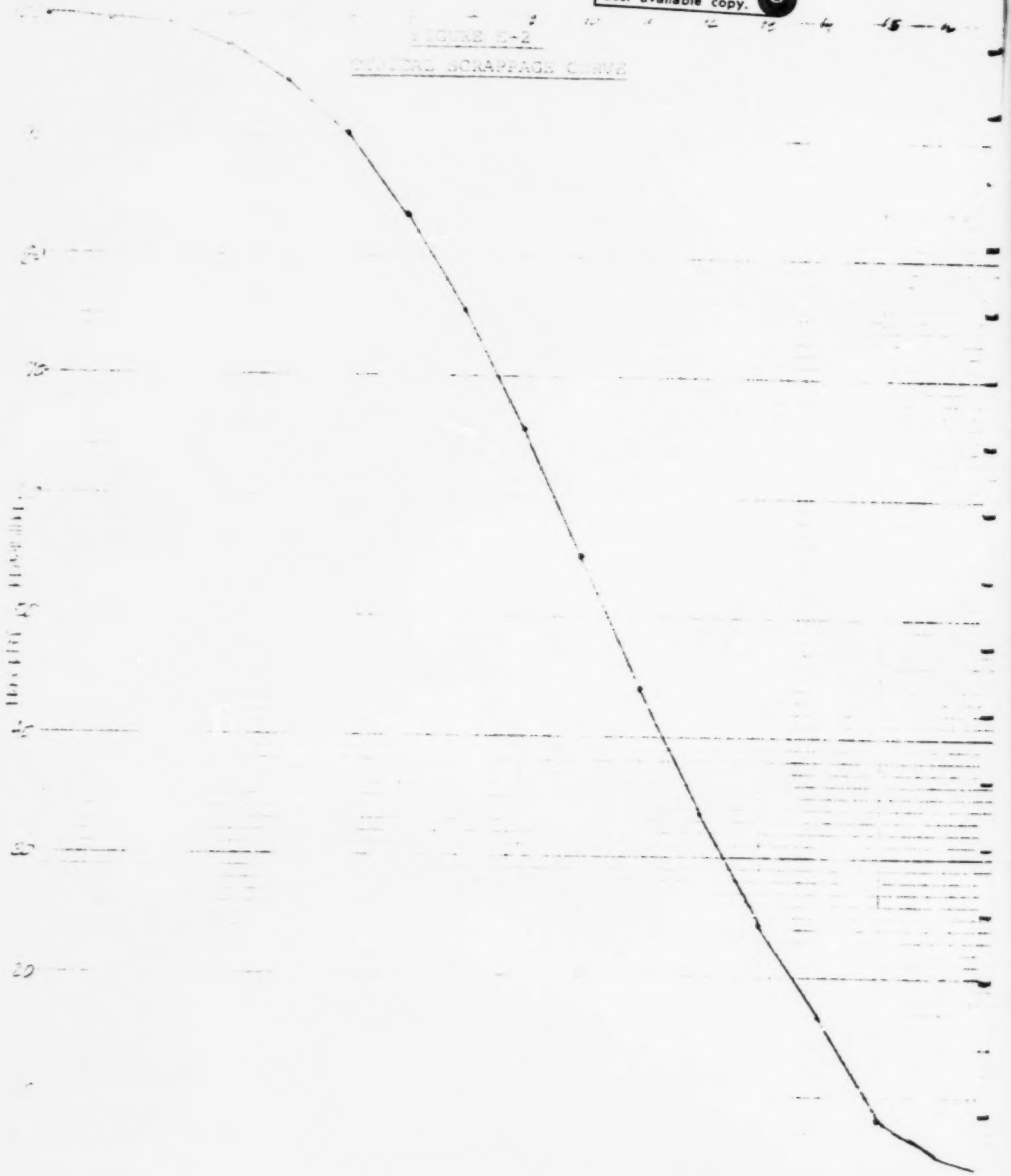


FIGURE E-3

AUTOMOBILE FUEL USE
Calendar Year 1977

Model Year	Automobiles: Original Registrations (10^6 autos)	Automobiles: Number Remaining (10^6 autos)	Average Miles Driven (miles)	Total Miles Driven (10^9 miles)	Average Fuel Base Rate (mpg)	Total Fuel Use (10^9 gal)
Prior 60	-	.1	6.1	.6	15.4	.04
60	6.6	.2	6.1	1.2	14.9	.08
61	5.8	.3	6.1	1.3	15.7	.11
62	6.9	.6	6.1	3.6	15.5	.23
63	7.6	1.0	6.1	6.1	13.7	.45
64	7.8	1.6	6.1	9.8	14.4	.68
65	9.3	2.4	6.1	14.6	14.0	1.04
66	8.6	3.2	6.1	19.5	14.2	1.37
67	7.4	3.5	6.6	23.1	14.4	1.60
68	8.8	5.1	8.0	40.8	13.4	2.83
69	8.2	5.6	8.7	48.7	13.5	3.61
70	6.5	5.0	9.3	46.5	13.5	3.44
71	8.6	7.4	9.1	67.3	13.7	4.92
72	10.4	9.5	10.1	95.9	13.5	7.10
73	11.7	11.2	10.4	116.5	13.7	8.50
74	10.3	10.1	11.4	115.1	14.0	8.22
75	11.3	11.2	12.8	143.3	15.0	9.55
76	11.7	11.7	14.7	172.0	15.0	11.47
77	11.9	11.9	16.5	196.4	15.2	12.92
78	12.0				15.2	
79	12.1				15.2	
80	12.5				15.3	
81	12.6				15.3	
82	12.9				15.3	
83	13.1				15.3	
84	13.3				15.3	
85	13.5				15.3	
86	13.7				15.3	
87	13.9				15.4	
88	14.1				15.4	
89	14.3				15.4	
90	14.5				15.4	
Total		101.6		1122.8		78.06

Fuel Use In Autos ($x10^b$ gal.)
Model Year Prior to 1976 53.67
Model Year 1976 and Later 24.39

FIGURE E-3b

AUTOMOBILE FUEL USE
Calendar Year 1980

Model Year	Automobiles: Original Registrations (10^6 autos)	Automobiles: Number Remaining (10^6 autos)	Average Miles Driven (miles)	Total Miles Driven (10^9 miles)	Average Fuel Base Rate (mpg)	Total Fuel Use (10^9 gal.)
Prior 60	-				15.4	
60	6.6				14.9	
61	5.8				15.7	
62	6.9	.1	6.1	.6	15.5	.04
63	7.6	.1	6.1	.6	13.7	.04
64	7.8	.3	6.1	1.8	14.4	.12
65	9.3	.6	6.1	3.6	14.0	.26
66	8.6	.7	6.1	4.3	14.2	.30
67	7.4	1.2	6.1	7.3	14.4	.51
68	8.8	1.9	6.1	11.6	13.4	.86
69	8.2	2.7	6.1	16.5	13.5	1.22
70	6.5	2.7	6.6	17.8	13.5	1.32
71	8.6	4.6	8.0	36.8	13.7	2.64
72	10.4	6.7	8.7	58.3	13.5	4.32
73	11.7	8.8	9.3	81.8	13.7	5.97
74	10.3	8.6	9.1	78.3	14.0	5.51
75	11.3	10.2	10.1	103.0	15.0	6.87
76	11.7	11.2	10.4	115.4	15.0	7.69
77	11.9	11.6	11.4	132.2	15.2	8.70
78	12.0	11.9	12.8	152.3	15.2	10.02
79	12.1	12.1	14.7	177.9	15.2	11.70
80	12.5	12.5	16.5	206.2	15.3	13.57
81	12.6				15.3	
82	12.9				15.3	
83	13.1				15.3	
84	13.3				15.3	
85	13.5				15.3	
86	13.7				15.3	
87	13.9				15.4	
88	14.1				15.4	
89	14.3				15.4	
90	14.5				15.4	
Total		108.4		1206.3		81.79

Fuel Use In Autos ($x10^6$ gal.)
Model Year Prior to 1976 30.11
Model Year 1976 and Later 57.68

FIGURE E-3c

AUTOMOBILE FUEL USE
Calendar Year 1985

Model Year	Automobiles: Original Registrations (10^6 autos)	Automobiles: Number Remaining (10^6 autos)	Average Miles Driven (miles)	Total Miles Driven (10^9 miles)	Average Fuel Base Rate (mpg)	Total Fuel Use (10^9 gal.)
Prior 60	-				15.4	
60	6.6				14.9	
61	5.8				15.7	
62	6.9				15.5	
63	7.6				13.7	
64	7.8				14.4	
65	9.3				14.0	
66	8.6				14.2	
67	7.4	.1	6.6	.7	14.4	.05
68	8.8	.1	6.6	.7	13.4	.05
69	8.2	.1	6.6	.7	13.5	.05
70	6.5	.2	6.6	1.5	13.5	.11
71	8.6	.6	6.6	2.4	13.7	.18
72	10.4	1.3	6.6	8.6	13.5	.64
73	11.7	2.2	6.6	14.5	13.7	1.06
74	10.3	2.8	6.6	18.5	14.0	1.32
75	11.3	4.4	7.0	30.1	15.0	2.01
76	11.7	5.8	8.6	49.9	15.0	3.32
77	11.9	7.2	9.3	67.0	15.2	4.40
78	12.0	8.5	10.0	85.0	15.2	5.59
79	12.1	9.6	9.7	93.1	15.2	6.13
80	12.5	11.1	10.8	119.9	15.3	7.84
81	12.6	11.8	11.1	130.1	15.3	8.50
82	12.9	12.6	12.2	153.7	15.3	10.05
83	13.1	13.0	13.7	178.1	15.3	11.61
84	13.3	13.3	15.7	208.0	15.3	13.65
85	13.5	13.5	17.7	239.0	15.3	15.62
86	13.7				15.3	
87	13.9				15.4	
88	14.1				15.4	
89	14.3				15.4	
90	14.5				15.4	
Total		118.3		1402.3		92.21

Fuel Use in Autos ($\times 10^6$ gal.)

Model Year Prior to 1976	5.47
Model Year 1976 and Later	86.74

FIGURE E-3$_c$

AUTOMOBILE FUEL USE
Calendar Year 1979

Year	Automobiles: Original Registrations (10^6 autos)	Number Remaining (10^6 autos)	Average Miles Driven (miles)	Total Miles Driven (10^9 miles)	Average Fuel Base Rate (mpg)	Total Fuel Use (10^9 gal.)
[illegible] 60)	-				15.4	
60	6.6				14.9	
61	5.8				15.7	
62	6.9				15.5	
63	7.6				13.7	
64	7.8				14.4	
65	9.3				14.0	
66	8.6				14.2	
67	7.4				14.4	
68	8.8				13.4	
69	8.2				13.5	
70	6.5				13.5	
71	8.6				13.7	
72	10.4				13.5	
73	11.7	.1	7.1	.7	13.7	.05
74	10.3	.3	7.1	2.1	14.0	.15
75	11.3	.5	7.1	3.6	15.0	.24
76	11.7	.8	7.1	5.7	15.0	.38
77	11.9	1.5	7.1	10.6	15.2	.70
78	12.0	2.2	7.1	15.6	15.2	1.03
79	12.1	3.3	7.1	23.4	15.2	1.54
80	12.5	4.7	7.7	36.2	15.3	2.27
81	12.6	6.1	9.3	56.7	15.3	3.71
82	12.9	7.7	10.1	77.8	15.3	5.08
83	13.1	9.3	10.8	99.4	15.3	6.56
84	13.3	10.7	10.6	113.4	15.3	7.41
85	13.5	12.0	11.7	140.4	15.3	9.18
86	13.7	12.9	12.1	156.1	15.3	10.20
87	13.9	13.3	13.3	176.9	15.4	11.56
88	14.1	14.0	14.9	203.6	15.4	13.55
89	14.3	14.3	17.1	244.5	15.4	15.88
90	14.5	14.5	19.3	279.8	15.4	18.17
Total		128.2		1631.5		108.18

Fuel Use In Autos
Model Year Prior to 1976 .44
Model Year 1976 and Later 107.74

FIGURE E-4

MAXIMUM ENERGY SAVINGS FROM INCREASED AUTO EFFICIENCY

(10^{12} BTU)

YEAR	PRIOR TO 1976 MODELS (tune ups)	1976 AND LATER MODELS (4 measures)	TOTAL SAVINGS
1977	365	810	1175
1980	205	1690	1895
1985	40	2790	2830
1990	0	3460	3460

APPENDIX F

TECHNICAL DISCUSSION OF TOTAL ENERGY SYSTEM

MATHEMATICA

APPENDIX F

TECHNICAL DISCUSSION OF TOTAL ENERGY SYSTEM[1]

The concept of total energy is deceptively simple: onsite power generation with waste heat recovery. The total energy system utilizes fuel such as gas or oil and may be operated independently of the local electric utility. The unique feature of total energy, as compared to conventional electric power generation, is the utilization of waste heat recovered from the generating process.

A dollar value can be assigned to this recovered waste heat, since its equivalent would have to be purchased in the form of other fuels or electricity to meet the thermal demands of the development being served. By systematically integrating several utility services and generating electricity locally, it is possible to recover normally wasted heat and utilize it to provide space heating, air conditioning, and domestic hot water. Another characteristic of onsite power generation is that power transmission and distribution lines are much shorter than utility company lines from a distant central power plant.

Onsite power generation is not new. In the early 1900's, nearly all large buildings and a substantial portion of American industry was supplied with electricity generated on the premises. Many early industrial onsite power plants utilized waste heat from manufacturing operations (shaft horsepower and process steam) to generate electricity, a variation of the current total energy concept. Although the amount of industrial onsite generation is increasing, the porportion of onsite generation, expressed as a percentage of total industrial electric consumption, has decreased. A variety of factors was responsible for the early growth of onsite power generation. These included a limited capacity of

---

[1]Reprinted from Economic Evaluation of Total Energy, HUD Report, HUD-DSC-1, 1973.

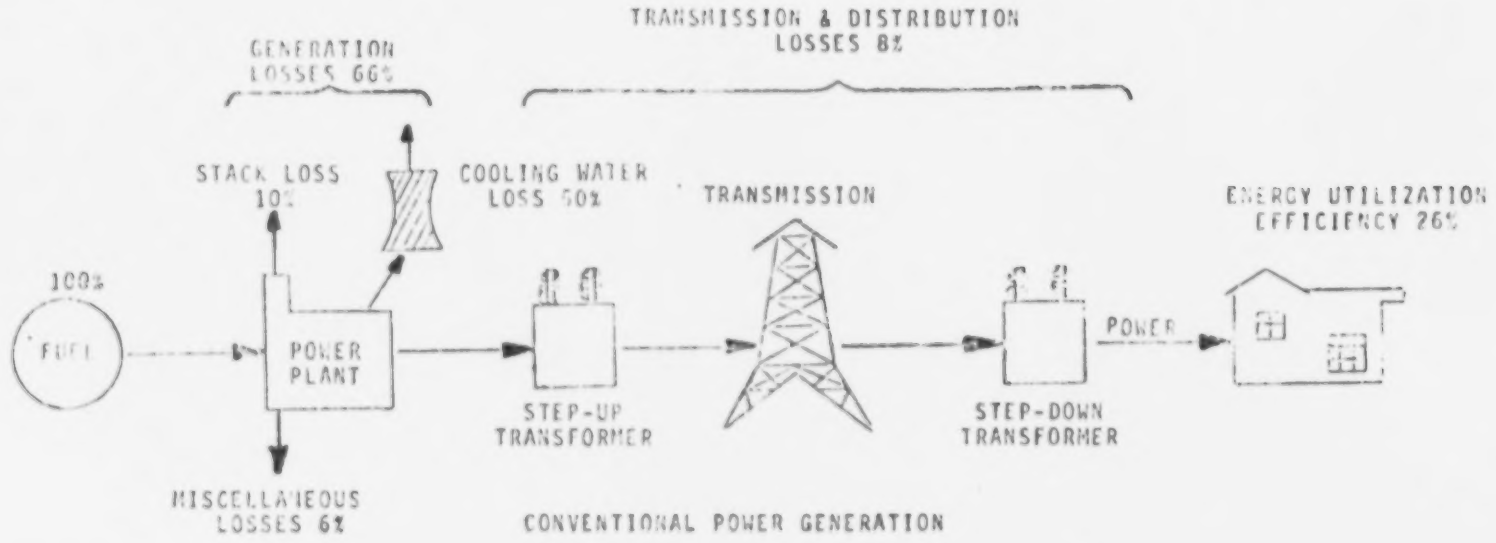
central generation plants, lack of adequate distribution systems, and high cost of purchased electricity. With the advent of high voltage transmission and decreasing costs of purchased power, the relative growth of onsite generation ceased.

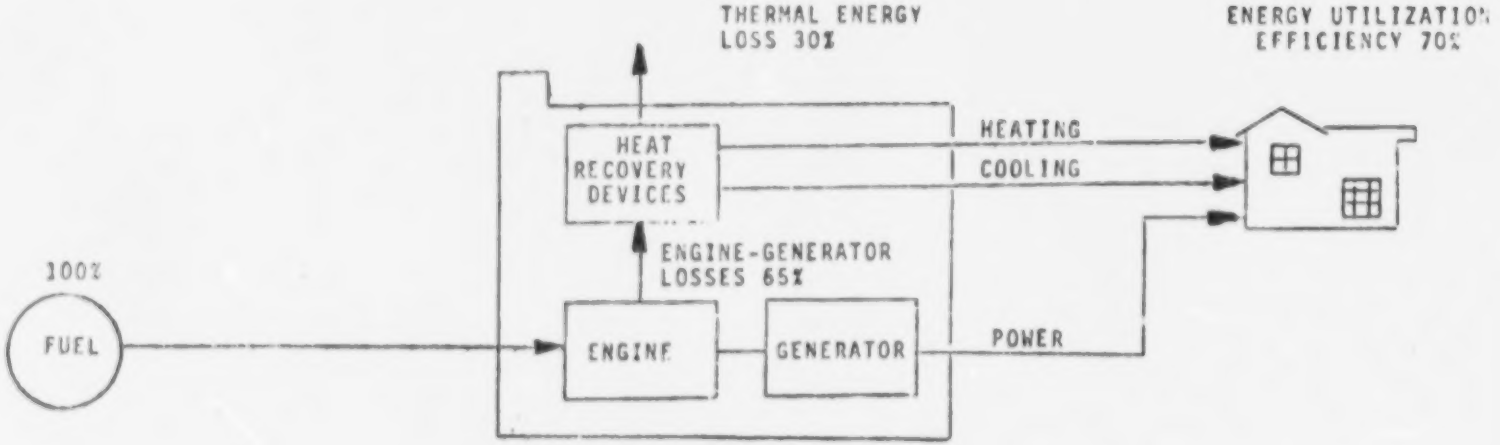
Unlike onsite power generation, the concept of waste heat recovery and utilization for heating and cooling is relatively recent. During the 1960's, total energy installations were made in such diverse applications as shopping centers, industrial plants, commercial buildings, motels, hospitals, schools, and multi-family residential projects. A number of factors contributed to the renewed interest in onsite power generation. Some are related to technical advances such as increased efficiency of heat recovery and the proven performance of absorption chillers. Other factors are related to life style: for example, the ever-increasing use of air conditioning. The summer energy requirements for air conditioning almost balance the winter demands for space heating, resulting in better overall utilization of recoverable waste heat. Other factors contributing to the renewed interest in total energy include the trend toward large-scale planned developments with substantial multi-unit construction. Rapidly escalating utility costs are making owners and operators of these developments increasingly aware of long-term owning and operating costs as opposed to earlier almost total concern with first costs. Energy systems with reduced energy requirements will become increasingly attractive as energy costs escalate, because energy conservation will mean substantial operating cost savings. The technology of total energy has now matured to a point where it can be considered as a primary contender to serve the energy needs of large-scale residential projects.

A typical total energy system is illustrated in Figure F-1. As shown, the total energy system consists of several carefully combined components:

FIGURE F-1

ENERGY UTILIZATION EFFICIENCY - CENTRAL STATION VS. TOTAL ENERGY





- Prime mover (reciprocating engine, turbine)
- Generator
- Waste heat recovery equipment
- Absorption chiller
- Heat exchange equipment
- Heat rejection equipment (cooling tower, etc.)
- Control system
- Distribution system

The prime mover drives a generator which supplies electric power. Waste heat is reclaimed from the exhaust and/or jacket cooling water to produce steam or hot water. This steam or hot water is then put to work to provide space heating, domestic hot water, and cooling. Absorption chillers provide the means of using waste heat to accomplish cooling. Since recovered waste heat is not always sufficient to meet total thermal demand, supplementary boilers and chillers, either absorption or centrifugal, are required in the total energy system.

The total energy system, recovering the waste heat of power generation can increase fuel use efficiencies by 100%.

APPENDIX G

COMPREHENSIVE LIST OF ENERGY CONSERVATION MEASURES

PEAT, MARWICK, MITCHELL

AND

MATHEMATICA

APPENDIX G

COMPREHENSIVE LIST OF ENERGY CONSERVATION MEASURES

ELECTRIC POWER GENERATION

Consumption Reduction

General Energy Conservation Measures (all sectors)

Increased Efficiency

Operational

Reduce peak load - even out diurnal demand
Fuel switches
Improved maintenance and repair

Hardware

Utilize municipal refuse as fuel
Speeded up design/construction of new units
Reduced waste heat discharge
Topping cycles
Advanced generation techniques (MHD)
Solid waste as fuel
Integrated Utilities MIUS
Reduced and more efficient street lighting
More efficient electric transmission
- Overhead
- AC and DC underground

More effective storage of energy
- Batteries
- Superconducting Magnet
- Flywheel
- Pumped hydroelectric

Better system security and control

Improved Energy Management

Data Base and MIS
Improved energy policy
Training
Year-round daylight savings time

Wastes as Fuels

Direct combustion
- coal & oil fuel boilers
- advanced techniques

Thermo-chemical conversion
Biogasification/Methane fermentation

Energy Delivery

Transmission and Distribution methods
Pipelines that are more leak resistant
Ship delivery systems
Arctic surface and submarine tankers
CNG tankers
Shallow draft tankers
Deepwater mooring ports
Loss control in storage and transfer

INDUSTRIAL SECTOR

Agricultural Services
Consumption Reduction

Increased use of natural fertilizers
Crop selection to minimize pesticide use
Use of natural (field) drying

Increased Efficiency

Operational

Crop selection to maximize yield
Equipment use (speed, load, etc.)
Optimum size plantings

Hardware

Power trains matched to load
Waste heat recovery, drying

Mining
Consumption Reduction

Recycling
Energy Conservation (fuel extraction)

Increased Efficiency

Operational

Equipment maintenance, repair

Hardware

Power to load matching
Efficient materials handling equipment
Fuel switches

Contract Construction

Consumption Reduction

- Reduce use of energy intensive materials
- Use inorganic wastes as construction material
- Oil-less asphalt

Efficiency Increase

Operational

- Optimal building size/design
- Construct for minimum (life-cycle) energy use
- Energy efficient techniques

Hardware

- Power to load matching
- Fuel switches

Manufacturing

General

Consumption Reduction

- Reduced use of energy intensive materials
- Eliminate consumption by idle or standby equipment or facilities
- Reduce illumination levels
- Reduce space heating and cooling requirements, i.e. air conditioning
- Locate facilities near efficient transport, efficient energy sources
- Total Energy System implementation

Increased Efficiency

Operational

- Upgrade maintenance and repair activities
- Procedures to minimize leaks and spills

Hardware

- Insulate buildings
- Insulate heated and cooled process equipment
- Reduce waste heat discharges (heat exchangers, waste heat boilers)

Food and Kindred Products

Consumption Reduction

Reduced use of packaging
Less convenience foods
Less energy absorbing processing

Increased Efficiency

Operational

Minimum cooking cycles
Recycle/utilize waste materials
Improved maintenance/repair

Hardware

Total energy systems
Increased insulation of heated and/or cooled equipment
Heat from combustion of agri. wastes
Heat exchangers for liquid and gaseous waste steams

Paper and Allied Products

Consumption Reduction

Recycling paper through all sections of economy
Decreased packaging/wrapping

Increased Efficiency

Operational

Fuel switches
Maximum use of energy efficient plants/processes
Improved maintenance/repair
Increased use of waste products as fuel

Hardware

Increased adoption of "dry" processes
Total Energy systems
Increased insulation of heated processes
Increased use of heat exchangers
Fuel switches
New plant design for minimum energy use

Chemicals and Allied Products

Consumption Reduction

Recycling
Increased use of low energy products

Increased Efficiency

Operational

- Four day work week and staggered work hours
- Improve maintenance and repair
- Improved scheduling of energy intensive operations
- Recycling energy intensive materials
- Reduced use of packing materials

Hardware

- Total energy systems
- Waste heat recovery systems-heat exchangers
- Fuel switches and more efficient fuel sources
- Design and install energy efficient processes/facilities
- More efficient material handling
- Solid waste fuel systems

Petroleum and Coal Products

Consumption Reduction

- Nationwide energy conservation policies
- Decrease production of energy consumption products

Increased Efficiency

Operational

- Improved maintenance and repair
- Reduce leaks, spills, wastage
- Improved processes
- Improved facilities locations

Hardware

- Total energy systems
- Heat exchangers and waste heat boilers
- Increased rate of phase-in for energy efficient plants/processes
- Coal gasification

Stone, Clay and Glass Products

Consumption Reduction

- Reuse of glass containers
- Efficient materials use in construction
- Less Polluting and energy absorbing cement manufacture
- Modified glass making process

Increased Efficiency

Operational

Improved maintenance and repair

Hardware

Fuel switches
Reduce direct heat requirements
Reduce waste heat discharges; heat exchangers
Insulate processes/buildings

Primary Metals

Consumption Reduction

Recycling metal scrap (especially Fe, Al)
Reduced material use in construction

Increased Efficiency

Operational

Reduce standby energy demand
Improved maintenance and repair
New, less energy intensive processes

Hardware

Phase out open hearth furnaces (steel)
Introduce efficient Al smelting processes
Fuel switches
Increase use of hot metal in processing
Waste heat recovery-heat exchangers
Energy efficient pollution control equipment
Recycle waste as fuel

COMMERCIAL SECTOR

Space Heating

Consumption Reduction

Operational

Reduce thermostats in winter
Four day work week
Individual temperature controls in apartment units

Building and Equipment

Fuel switch
Const./Design changes

Total Energy System
Flue Gas Heat Recovery
Dual Pane Glass
Solar Heat
Energy Budgets

Increased Efficiency

Operational

Reduced work week to four days
Reduced heat exchange losses

Buildings and Equipment

Improved insulation
Efficient furnaces-required furnace inspection
Energy-efficient design - e.g. double sets of doors required
Heat pumps
Reduce leakage through windows and doors, smaller surface areas

Air Conditioning

Consumption Reduction

Operational

Increase thermostat in summer
Delamping
Revise summer dress codes, e.g. no ties or jackets

Buildings and Equipment

Energy saving design changes
Reflective windows
Dual pane glass
New equipment technology
Improved insulation for new buildings
Direction of building overhangs

Increased Efficiency

Operational

Optimize workload production periods
Utilize air flow only-open windows
Air recycle air-conditioning

Buildings and Equipment

Retrofit adjustment
Match equipment to needs
Reduce intake of outside air-Eleotrotratic, charcoal or smaller equipment
Absorbers
Upgrade insulation in existing buildings
Heat pumps
Reduced airflow

Water Heating, Refrigeration, Cooking, Lighting and Other

Consumption Reduction

Operational

Shut-off lighting policy
Mandatory electrical outdoor display restrictions
Task lighting

Hardware

Solar Hot Water heaters

Increased Efficiency

Operational

Locate water heaters near end use

Hardware

Insulate hot water pipes
Upgrade appliances for efficiency
Switch to florescent from incandescent

Business Practices

Restrict sizes of commercial delivery vans
Require business to urge customers to use mass transit

RESIDENTIAL SECTOR

Space Heating

Consumption Reduction

Operational

Oil heat in new homes
Turn off gas furnace pilot lights in summer
Total energy system in multi-units
Lower thermostat in winter
Establish furnace efficiency inspections
Establish mandatory furnace efficiency requirements

Hardware

Solar heat
Improved furnace equipment
Total Energy system in multi-units
Flue gas heat recovery
Switch to florescent lighting
Heat pumps

Increased Efficiency

Operational

Establish minimum efficiency standards
Public Educational conservation programs
Reduce heat exchange losses

Hardware

Retrofit storr windows and doors
Improved furnace
Storm windows and doors on new buildings
Install R-19 ceiling insulation
Wall insulation

Air Conditioning, Water Heater, Cooking, Clothes Drying, Refrigeration, Other

Consumption Reduction

Operational

Increase thermostat in summer

Hardware

Better insulation for water heaters and piping
Open air cycle air conditions
Establish Appliance Consumption ratings & requirements for OEM's
Locate water heater nearer end use
Substitute electric ignition for gas pilot lights

Increased Efficiency

Operational

Switch fuels
Elimination of non-returnable containers
Frost-free vs. standard refrigeration

Hardware

Improved appliances
Switch to gas dryers from electrical

Location of Residence Building Practices

Require that builders show alternative transportation (other than auto) is available to residents

Energy impact statements for location and building of residences

Encouraging adjoining wall (row house) construction

Deciduous tree planting to shade houses in summer

Direction of buildings

TRANSPORTATION SECTOR

PASSENGER

Automobiles

Consumption Reduction

Intracity

better land use
carpools
mass transit expansion
new mass transit
reduce pleasure travel
encourage bicycles and walking

Intercity

Increased communication
shift to bus
shift to rail
reduce pleasure travel
regional recreational improvements

Increased Efficiency

Operational

new less energy-costly fuel or fuel mixtures
reduced speed limits
tune-ups required every six months or 5000 miles
improved traffic control

Hardware

radial tires
small cars-tax on size/power
engine efficiency and modifications
aerodynamic configuration
vehicle weight
new types of advanced engines
Rankine Cycle
Brayton Cycle
Sterling Cycle
Stratified charge
Light Diesel
Air
Hy
B ine mixture
cera ents
addi ent pollution control equipment

Buses

Consumption Reduction

increased load factors

Increased Efficiency

Operational

reduced speed limits
tuneups
schedule efficiency
better scheduled service
less costly as incentive to riders

Hardware

radial tires
fuel conversion
engine efficiency

aerodynamic configuration
vehicle weight
optimal bus size
flywheel incorporation in system

Air Transport

Consumption Reduction

increased communication
shift to bus/rail
increase load factors

Increased efficiency

Operational

speed reductions/altitude control
schedule efficiency
aircraft routing

Hardware

optimal aircraft size
fuel switches

Rail Transport

Consumption Reduction

Increase load factors
increase communication

Increased efficiency

Operational

schedule efficiency
optimal train sizes

Hardware

fuel switch
upgrade track

FREIGHT

Trucks

Consumption reduction

shift to rail/boat/pipeline

Increased efficiency

Operational

clustering shipments
larger shipments
piggyback/containerization
reduced speeds
backhauling
gateway regulation
consolidated delivery

Hardware

tandom rigs/powered and unpowered
radial tires
load to engine
aero drag
fuel change
improved engines with better economy
flywheels

Rail

Consumption reduction

Increase load factor

Increased Efficiency

Operational

schedule efficiency
optimal train sizes
unit trains
containerized freight
consolidated delivery

Hardware

fuel switch
upgrade tracks
improved equipment
engine improvements
flywheels

Consumption reduction

mode shift to bus, trains and truck
increase load factor

Increased Efficiency

Operational

optimal aircraft size
ground operation
speed reduction/altitude control
aircraft routing
scheduling efficiency
containerization
consolidated delivery

Hardware

fuel switches
more efficient engines
back to props

Water/Pipelines

Increased usage

Ships

Advanced machinery
increased usage - shift from other modes
alternative fuels - nuclear propulsion

Communications

Substitute for travel

APPENDIX H

TEST APPLICATION RESULTS OF

EVALUATION AND RANKING METHODOLOGY

PEAT, MARWICK, MITCHELL

APPENDIX H

TEST APPLICATION RESULTS OF EVALUATION AND RANKING METHODOLOGY

I. INTRODUCTION

The basic methodology steps and uses are presented in the main text. This appendix summarizes the conservation measure evaluation and ranking methodology procedures and computations not detailed in the main text. Appendix A is divided into the following sections:

Evaluation

- implementation strategy postulation;
- feasible energy savings estimates; and
- impact estimates.

Ranking

- scaling
- weighting
- scoring
- ranking

II. EVALUATION

Implementation Strategies

An implementation strategy was postulated for each conservation measure. The criteria used as a basis for implementation strategy postulation were:

- practicability - was the implementation strategy practical in terms of enactment, administration and achievability;
- time-frame - was the implementation strategy the best strategy to obtain maximum savings in the shortest period of time;
- environmental conflict - did the implementation strategy directly conflict with existing or planned environmental programs; and
- controversiality - was the implementation strategy presently subject to strong public opinion.

While each of these criteria enter into the evaluation process at a subsequent point in the analysis, they were applied initially on an intuitive level to assist in selection of a reasonable set of implementation strategies. Postulation of implementation strategies was accomplished by first reducing potential strategies to the following basic mechanisms:

- voluntary;
- price control;
- supply/demand control;
- legislative mandate;
- regulatory mandate; and
- tax policy.

Then, one, or a combination of the above mechanisms, was judgmentally selected for each measure. The selected mechanisms were in turn expanded and explicitly defined. For example, a tax policy mechanism for the home insulation retrofit measure was defined as a 50 percent tax credit against the total installation cost.

Feasible Energy Savings Estimates

Feasible energy savings were defined as that proportion of maximum technologically feasible savings in BTUs that could actually be achieved when development, logistics, political, legislative and attitudinal factors were taken into account. The maximum technologically feasible savings used in this analysis were taken from Mathamaticas' Analysis and Synthesis of EPA Energy Conservation studies.

To determine the proportion of maximum energy savings actually achievable, each measure and the implementation strategy associated with that measure was qualitatively evaluated using the following criteria:

Developmental feasibility

- research time required before implementation;
- development time required before implementation;

Logistical feasibility

- facilities available for production requirements;
- materials distribution system available to provide required materials;

- information dissemination mechanisms or time required for implementation;

Economic feasibility

- economic feasibility of measure;
- marketability of measure;

Political/legislative feasibility

- enabling legislative requirements;
- legal precedent to provide basis for implementation;
- feasibility of required legislation;
- government authority limitations for implementation by mandate or other controls;
- capability to enforce or control once implemented;

Attitudinal feasibility

- willingness of the public to accept or comply with measure;
- willingness of industry to accept or comply with measure.

These criteria were applied by qualitatively assessing implementation time requirements, probability of implementation and probable level of compliance. Since most of these criteria are not readily quantifiable, the assessments were made judgmentally based upon available data, e.g., attitudinal surveys, past experience or expert opinions. Where no data were available, no adjustment to estimated energy savings was made for that criteria.

For each measure, an assessment of estimated achievable energy savings for each forecast year was made by consolidating the evaluation

into a single percentage of total savings that could be achieved. This percentage was applied to the maximum technologically feasible estimate of savings to determine achievable savings. Applications of this process are presented for each measure in the main text of this report.

Impact Estimates

Energy conservation measure impacts were defined as the economic, social and environmental impacts which could result if the measure was implemented using the postulated strategy and producing the level of savings suggested by the estimate of achievable energy savings. In most cases, the impact estimates were confined to directly affected industries. Secondary impacts such as suppliers to directly affected industries were not estimated. The impacts included in the analysis are as follows:

- private industry revenue impact;
- private consumer added costs or savings;
- government added costs or revenue losses;
- balance of payments (decrease in oil import value);
- environmental changes in air, water and solid waste;
- employment increases and/or decreases;
- materials resources, scarce materials; and
- quality of life changes in mobility, comfort and convenience.

Within the scope of the analysis, it was not possible to estimate values for every impact for every measure. Where estimates were not possible, zero impact was assumed. While this assumption tends to bias the ranking, the bias is minimized since the zero assumption neither adds to nor detracts from the measure for which the impact was not calculated, and the zero assumption is usually only one impact out of eight.

While the ranking under this analysis does reflect this bias, it does provide a systematic comparison and trade-off based upon available data. The bias can be eliminated in future applications by developing better data inputs for each measure in question or, where data is not available for a specific measure, but the general impact is known, the bias can be accounted for with a qualified adjustment by the analyst.

The assumed energy mixes for each sector are shown in Table A-1. In each sector, the average projected energy consumption mix between 1977 and 1990 was assumed for the analysis. It should be noted that the energy mixes presented in Table A-1 are not the same mix assumed by Mathematica for estimation of maximum feasible energy savings. However, the difference between the mixes assumed for impact analysis and the mixes assumed for energy savings does not significantly affect the impact estimates with respect to energy savings estimates, since the impact estimates are relative. In other words, the impact values are estimated on the same basis for each measure and each measure is evaluated with respect to one another. Hence, a shift in the assumed energy mix, would affect each measure in the same manner, with no impact on the ranking process.

TABLE A-1

UNITED STATES TOTAL GROSS CONSUMPTION OF ENERGY RESOURCES BY MAJOR SOURCES AND CONSUMING SECTORS, 1971 ACTUAL, AND PROJECTIONS TO YEAR 2000 (IN TRILLIONS OF BTU's)

	Coal[1]	Petroleum[2]	Natural gas	Total fossil fuels	Nuclear power	Hydro power	Total gross energy inputs	Synthetic gas distributed	Total four sector inputs	Utility elec. distributed	Total three sector inputs
1971 Household & Commercial	390	6,545	7,346	14,281			14,281	-	14,281	2,160	17,441
Industrial	4,485	5,391	10,418	20,294			20,294	-	20,294	2,329	22,623
Transportation	7	16,139	825	16,971			16,971	-	16,971	18	16,988
Electrical Generation	7,698	2,417	4,125	14,240	405	2,798	17,443	-	17,443	(5,507)	-
Synthetic Gas	-	-	-	-	-	-	-	-	-	-	-
Total	12,560	30,492	22,734	65,786	405	2,798	68,989				
1975 Household & Commercial	325	6,950	8,660	15,935			15,935	-	15,935	4,240	20,175
Industrial	4,600	6,510	11,740	22,850			22,850	-	22,850	3,010	25,860
Transportation		18,050	1,020	19,070			19,070	-	19,070	20	19,090
Electrical Generation	8,900	3,580	3,800	16,280	2,560	3,570	22,410	-	22,410	(7,270)	-
Synthetic Gas	-	-	-	-	-	-	-	-	-	-	-
Total	13,825	35,090	25,220	74,135	2,560	3,570	80,265				
1980 Household & Commercial	300	7,720	9,480	17,500			17,500	320	17,820	6,040	23,860
Industrial	4,750	7,590	12,500	24,840			24,840	380	25,220	4,170	29,390
Transportation		21,440	1,400	22,840			22,840	-	22,840	30	22,870
Electrical Generation	10,660	5,000	3,600	19,260	6,720	3,990	29,970	-	29,970	(10,240)	-
Synthetic Gas	430	440		870			870	(700)	-	-	-
Total	16,140	42,190	26,980	85,310	6,720	3,990	96,020				
1985 Household & Commercial	100	8,800	10,060	18,960			18,960	940	19,900	7,800	27,700
Industrial	5,150	9,130	13,240	27,520			27,520	1,060	28,580	6,290	34,870
Transportation		25,450	1,640	27,090			27,090	-	27,090	40	27,130
Electrical Generation	14,220	6,650	3,450	24,320	11,750	4,320	40,390	-	40,390	(14,130)	-
Synthetic Gas	2,000	670		2,670	-	-	2,670	(2,000)	-	-	-
Total	21,470	50,700	28,390	100,560	11,750	4,320	116,630				
2000 Household & Commercial		11,120	10,800	21,920			21,920	2,640	24,560	15,070	39,630
Industrial	6,700	14,660	17,940	39,300			39,300	2,860	42,160	15,620	57,780
Transportation		40,010	2,600	42,610			42,610	-	42,610	50	42,660
Electrical Generation	17,520	5,040	2,840	25,200	49,230	5,950	80,380	-	80,380	(30,740)	-
Synthetic Gas	2,140	550		2,690			2,690	(5,500)	-	-	-
Total	31,360	71,380	34,180	136,720	49,230	5,950	191,900				

[1] Includes anthracite, bituminous, and lignite.

[2] Petroleum products refined and processed from crude oil, including still gas, liquefied refinery gas, and natural gas liquids.

Source: "U.S. Energy Through the Year 2000," U.S. Department of Interior, 1972.

Private Industry, Private Consumer, and Government Impacts

Private industry, private consumer and government impact estimates were each computed based upon the specific conservation measure and are detailed in the main text.

Private industry impacts focused upon direct revenue losses or gains which would accrue to industries directly affected by the measure, (e.g. Bus transportation companies would gain revenues as a result of increased ridership generated by the conservation measure. Added revenues were based on estimated increased passenger miles.)

Where capital costs were identified (e.g. added bus fleet requirements), the total capital cost was discounted at 10 percent over the assumed economic life of the capital improvement.[1/]

Consumer impacts were confined to direct added costs or savings resulting from the conservation measure (e.g. reduced energy costs or added costs for equivalent services). Where a capital expenditure was required (e.g. retrofit storm windows), discounted annualized capital costs were included.[1/]

Government impacts (except balance of payments) were confined to Federal level direct tax revenue losses and programmatic costs. The revenue losses were based upon the assumed tax incentive rate or the average tax in force (e.g. gasoline tax was assumed to be $0.11 per gallon).

1/ Annualized discounted capital cost $= \frac{\text{capital cost} \times \text{annual discount rate}}{1 - \left[1/(1 + \text{discount rate})\right]^{\text{years (economic life)}}}$

Balance of Payments

Balance of payment impact estimates were made only for the estimated oil imports avoided. Avoided imports were estimated on the assumption that between 1977 and 1990, approximately 18 percent of oil consumption would be imported. The import estimate was then based on 18 percent of the proportion of oil-supplied energy consumed by a particular sector. A price of $11.40 per barrel was assumed. The general formula used was:

$ import avoidance = price per BTU x BTU savings x .18

The factors used in the study are presented in Table A-2.

Environmental Impacts

Environmental impacts of the energy conservation measures have been measured in terms of certain pollutant reductions entailed with energy consumption reductions. As an approximation, these specific impacts serve as general environmental indicators.

TABLE A-2

BALANCE OF PAYMENT FACTORS

[illegible]	- [illegible]
[illegible]	- [illegible]
Percent import	- 18

Residential/commercial [1]	1977	1980	1985	1990
Proportion sector oil use assumed	.34	.32	.32	.31
Factor	1.1×10^{-7}	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}
Power generation [1]				
Proportion sector oil use assumed	.24	.26	.27	.25
Factor	7.8×10^{-8}	8.5×10^{-8}	8.8×10^{-8}	8.2×10^{-8}
Transportation				
Proportion sector oil use assumed	100	100	100	100
Factor	3.2×10^{-7}	3.2×10^{-7}	3.2×10^{-7}	3.2×10^{-7}
Industrial				
Proportion sector oil use assumed	.26	.26	.26	.26
Factor	8.3×10^{-8}	8.3×10^{-8}	8.3×10^{-8}	8.3×10^{-8}

[1] Exceptions - Appliances - all electric, power generation factors used.
Ventilation - all electric, power generation factors used.
Airflow - all electric, power generation factors used.
Task lighting - all electric, power generation factors used.
Pyrolysis - displaces natural gas - no balance of payment impact estimated.

Air pollution is one of the most direct environmental effect of fossil fuel consumption. Energy conservation measures, by effecting a reduction in fuel use, will thus, reduce the air pollution problem. The specific pollutants caused by fuel combustion vary by energy consuming section. Table A-3 shows the principle pollutant(s) produced within each sector and the projected national totals for each. These estimates assume the continuation of present air pollution control practices. In terms of air pollution, the environmental impact of each control measure was estimated in the following manner.

- the percentage reduction in fuel consumption with the sector was computed;
- this percentage was used to determine the quantity of air pollution emissions avoided; and
- the percentage reduction in total emissions was computed using the estimated reduction and total emissions estimate.

In this way, the environmental impacts of various energy conservation techniques, applied to different consuming sectors, could be presented in a consistent and comparable manner. In this analysis, pollutant emissions serve as a surrogate for ambient air quality and no attempt was made to introduce the locational or meterological considerations necessary for a detailed air pollution evaluation.

For the commercial, residential, and power generation measures, SO_2 reductions were measured in the following way. Using projected energy consumption data, the BTU reduction of oil, gas, and coal use was calculated by given measures for given years. These reductions were multiplied by appropriate SO_2 emission factors given in Reference Energy Systems and Resource Data for Use in Assessment of Energy Technologies, Associated

TABLE A-3
REPRESENTATIVE POLLUTANTS: ANNUAL EMISSIONS
BY SECTOR AND AGGREGATE TOTAL

ENERGY CONSUMING SECTOR	1977	1980	1985	1990
Residential and commercial				
SO_2 (lbs. x 10^6)	1,515	1,610	1,835	1,991
Industrial				
SO_2 (lbs. x 10^6)	18,930	20,895	27,085	34,495
Particulates (lbs. x 10^6)	12,200	13,250	15,000	16,200
Transportation				
Hydrocarbon (lbs. x 10^6)	24,260	19,300	16,100	15,700
Carbon monoxide (lbs. x 10^6)	173,450	135,440	72,440	61,500
Electric power generation				
SO_2 (lbs. x 10^6)	29,145	33,640	44,680	48,202
National Totals				
SO_2 (lbs. x 10^6)	51,140	57,900	75,900	87,334
CO (lbs. x 10^6)	175,000	137,000	73,000	63,800
Particulates (lbs. x 10^6)	22,400	23,900	26,500	27,700
Solid waste (tons x 10^6)	202	211	226	242
Hydrocarbons (lbs. x 10^6)	26,600	20,700	17,500	16,600

Source: Derived from Reference Energy Systems Resource Data for Use in Assessment of Energy Technologies, Associated Universities, Inc., Upton, New York, 1973 (AET-8.)

Corporation, Inc., Lyon, New York, 1973 (generally referred to as "AET-8",) using values of 0.2% sulfur content of fuel oil and 2.0% sulfur content of coal. Sulfur was assumed to be otherwise uncontrolled. Hence, SO_2 emission reductions for given measures, as well as total overall SO_2 emissions cited are uncontrolled ones.

Industrial particulate emissions are related to specific processes and processing rates rather than to fuel combustion. Environmental impacts using this pollutant indicator were computed using the change in consumption of the industrial product (e.g., fertilizer) rather than energy consumption change to determine the potential affect of the conservation measure.

For the transportation sector, HC and CO reductions were measured using AET-8 emission factors for transportation gasoline and diesel fuels for comparison with total emissions. Transportation sources account for much of the HC and nearly all of the CO emissions, and we assumed as given in AET-8, continual reductions in HC and CO emissions through 1990 due to the Federal Motor Vehicle Control Program.

For the industrial and power generation sectors, solid waste tonnage reductions were calculated directly from energy reduction calculations. Total solid waste, as given in Table A-3 was calculated on the basis of a constant 5 lbs. per person per day solid waste generation in the U.S., with population figures from U. S. Bureau of the Census, series E projections.

Data for industrial thermal pollution emissions is generally not available; hence, thermal pollution reduction impacts from energy conservation measures were not calculated for the industrial sector. For the case of electric power generation, however, AET-8 indicates that for every 10×10^{12} BTU used for electrical power generation in fossil fuel plants,

[illegible] a heat rate of 32.6%, contributes to thermal pollution. We used this thermal pollution indicator for our calculations concerning power generation conservation measures.

Employment

Employment estimates were made only for the transportation and industrial sectors. Insufficient data was available to assess added or decreased employment impacts where applicable in the other sectors, (e.g., new solar industry.) Finally, in certain cases (e.g., thermostat control) no significant employment impact was assumed.

Transportation employment impacts were based upon average wages per employee and on an assumed proportion of labor cost to total costs as revenues. The employment impact was calculated using the following general formula:

$$\text{added (lost) employment} = \frac{P \times \text{added or lost revenue}}{\text{mean industry wage}}$$

where P = proportion of labor cost to total cost or revenues.

The specific assumptions are detailed in the main text.

Industrial sector employment impact was estimated based upon an employment per dollar revenue ratio. The employment per dollar revenue ratio used was developed based upon the 1973 U.S. Industrial Outlook, published by the U.S. Department of Commerce and upon B. Hannon's (University of Illinois) ratios of employment per final dollar of demand. The general formula for estimation of industrial employment impact is as follows:

added (lost) employment = added (lost) revenue x employment ratio.

where employment ratio = $\frac{\text{industry aggregate employment 1973}}{\text{industry aggregate revenue 1973}}$

[illegible] industries were involved, employment impact for each [illegible] was estimated from the [illegible] employment impact used. If primary data collection was undertaken, or more detailed industry data collected, better estimates of employment could be made based upon current output ratios for the specific industry in question.

Materials Resources and Quality of Life Impacts

Very little hard data was available to quantify material resources problems and quality of life impacts. The impact estimates used in this study were developed on a qualitative basis and presented in narrative form. For purposes of evaluation and ranking, relative scores between zero and 10 were assigned for each measure based upon the qualitative analysis. These assignments were a result of a consensus of the researchers' judgments developed in group sessions. The scores are shown in Tables A-4 and A-5.

Ranking

The ranking process was accomplished in four steps: scaling, weighting, scoring and ranking. Following are the computational procedures used in ranking the 26 measures.

Scaling

To simplify the ranking process, the scaling process was designed to display all impacts as positive relative values. This step eliminates the laborious handling of signed numbers in the ranking process and simplifies the final display. This means that relative scores close to zero tend to be poor relative to high scores.

Feasible energy savings and each impact was placed upon a relative scale of 0 to 10. To accomplish this, the most desirable value for a specific impact was set equal to 10, and the least desirable value for that impact was set equal to zero.[1/] The intermediate values for that impact were

1/ For display purposes, the final scores were multiplied by 10, i.e., 0-100 scale to better illustrate the relative ranks of each measure.

TABLE A-4

CUMULATIVE 1977 - 1990 UNWEIGHTED IMPACT SCORES

MEASURE	CODE	SAVINGS BTUs x 10^{12}	PRIVATE INDUSTRY	PRIVATE CONSUMER	GOV'T.	BAL. OF PAYMENT	IMPLY.	ENVIRON.	FIN. RISK	[illegible]
Space heat	B-1	4,237	2.5	1.1	9.7	0.5	6.1	1	3.3	[illegible]
Insulation	B-2	3,023	3.7	0.8	9.3	.3	6.1	2	3.3	[illegible]
Appliances	B-3	23,288	1.0	10.0	9.7	2.3	6.1	7	3.3	[illegible]
Thermostat	B-4	8,786	1.0	2.4	9.7	0.9	6.1	2	3.3	[illegible]
Solar	B-5	3,577	4.4	0.9	9.4	0.4	6.1	2	0.0	[illegible]
Ventilation	C-1	15,819	10.0	0.8	9.7	1.4	6.1	6	3.3	[illegible]
Air flow	C-2	1,700	2.0	0.8	9.7	0.1	6.1	3	3.3	[illegible]
Task lighting	C-3	2,970	3.3	0.8	9.7	0.3	6.1	4	3.3	[illegible]
Thermostat	C-4	11,143	8.0	0.8	9.7	1.2	6.1	3	3.3	[illegible]
IES	C-5	299	1.2	0.8	9.7	.03	6.1	1	3.3	[illegible]
Solar	C-6	673	1.4	0.8	9.7	.06	6.1	1	3.3	[illegible]
Fertilizer	I-1	670	0.4	1.1	9.7	.05	5.0	2	10.0	[illegible]
Packaging	I-2	2,293	0.0	1.3	9.5	0.2	0.0	9	3.3	[illegible]
IES	I-3	851	1.3	0.9	9.7	.07	6.1	3	3.3	[illegible]
Recycle	I-4	1,093	1.2	8.6	7.9	.09	6.1	8	10.0	[illegible]
Returnables	I-5	3,048	1.5	1.6	10.0	.3	6.1	8	3.3	[illegible]
Intercity trans.	T-1	1,769	7.3	0.0	6.2	0.5	10.0	3	3.3	[illegible]
Carpools	T-2	13,696	1.0	6.3	5.4	4.4	6.1	5	3.3	[illegible]
Shift to bus	T-3	5,025	6.3	1.3	4.2	1.6	9.6	4	3.3	[illegible]
TOFC/COFC	T-4	135	1.5	0.8	9.7	0.1	7.0	4	3.3	[illegible]
Auto efficiency	T-5	31,089	1.0	0.8	0.0	10.0	6.1	0	3.3	[illegible]
Direct firing	P-1	4,602	2.1	0.9	9.7	0.0	6.1	10	3.3	[illegible]
Pyrolysis	P-2	340	0.9	0.8	9.6	0.0	6.1	6	10.0	[illegible]
Bioconversion	P-3	247	1.0	0.8	9.7	0.0	6.1	6	10.0	[illegible]
Wind	P-4	501	.04	0.8	9.7	0.1	6.1	3	3.3	[illegible]
Waste heat	P-5	47,547	4.9	0.8	9.7	1.3	6.1	9	3.3	[illegible]

Measure	Code	Savings BTUs x 10^{12}	Pvt. Indust.	Pvt. Comm.	Gov't.	Bal. of Payst.	Employ.	Environ.	Resource Mat.	Quality of Life
Space heat	R-1	523	3.4	2.3	9.4	0.5	6.1	1	3.3	10.0
Insulation	R-2	325	3.7	2.1	9.2	0.3	6.1	2	3.3	10.0
Appliances	R-3	2863	2.4	10.0	9.4	2.1	6.1	7	3.3	6.6
Thermostat	R-4	717	2.4	3.0	9.4	0.6	6.1	2	3.3	6.6
Solar	R-5	683	6.3	2.1	9.1	0.6	6.1	2	0.0	10.0
Ventilation	C-1	1657	10.0	2.0	9.4	1.5	6.1	6	3.3	3.3
Air flow	C-2	206	3.2	2.0	9.4	0.15	6.1	3	3.3	3.3
Task lighting	C-3	321	4.1	2.0	9.4	0.24	6.1	4	3.3	10.0
Thermostat	C-4	1000	6.7	2.0	9.4	0.93	6.1	3	3.3	6.6
TES	C-5	55	2.6	2.0	9.4	0.05	6.1	1	3.3	10.0
Solar	C-6	127	2.9	2.0	9.4	0.11	6.1	1	3.3	10.0
Fertilizer	I-1	53	2.1	2.2	9.4	0.04	5.0	2	10.0	10.0
Packaging	I-2	917	0.0	3.3	8.9	0.7	0.0	9	3.3	0.0
TES	I-3	148	2.7	2.0	9.4	0.11	6.1	3	3.3	10.0
Recycle	I-4	214	2.6	2.0	6.3	0.16	6.1	8	10.0	10.0
Returnables	I-5	568	3.0	3.1	10.0	0.42	6.1	8	3.3	6.6
Intercity Trans.	T-5	263	9.2	0.0	6.9	0.8	10.0	3	3.3	10.0
Carpools	T-2	1167	2.4	5.8	6.3	3.4	6.1	5	3.3	6.6
Auto Efficiency	T-5	3464	2.4	8.7	0.0	10.0	6.1	0	3.3	10.0
Shift to Bus	T-3	575	6.3	2.5	4.0	1.7	9.6	4	3.3	10.0
TOFC/COFC	T-4	18	2.8	2.0	9.4	0.1	7.0	4	3.3	10.0
Direct Firing	P-1	759	3.5	2.1	9.4	0.0	6.1	10	3.3	10.0
Pyrolysis	P-2	80	2.3	2.0	9.3	0.0	6.1	6	10.0	10.0
Bioconversion	P-3	58	2.4	2.0	9.4	0.0	6.1	6	10.0	10.0
Wind	P-4	137	2.2	2.0	9.4	0.1	6.1	3	3.3	10.0
Waste heat	P-5	7451	6.9	2.0	9.4	1.9	6.1	9	3.3	10.0

[illegible] ranging between zero and one based upon simple [illegible] The general formula used to scale a specific raw [illegible] score is as follows:

$$\text{relative impact score} = \frac{\text{raw impact score}}{\text{raw impact score range}}$$

where: the raw impact score range equals the highest raw score for that impact less the lowest raw score for that impact for all measures under evaluation. Tables A-4 and A-5 present the relative scores for each measure and impact in the analysis.

Weighting and scoring

The relative impact scores for each measure must be aggregated to a single impact value for comparison against the relative energy savings score. If every impact was considered exactly as important as every other impact, the relative impact scores for a specific measure could be simply added and divided by eight to obtain a relative impact score between zero and one.

If the impacts are not considered equal, it is necessary to weight each impact relative to each other impact. For example, if employment impact is considered twice as important as industry impact, then total impact (employment and industry) is computed as follows:

Total impact = (.67 x relative employment impact) + (.33 x relative industry impact)

In the above example, employment impacts would affect the final score twice as much as industry impact. Since the relative importance of each impact is judgmental, the weights must be set by the evaluators.

To establish the relative weights for each measure, a survey questionnaire was used to determine the relative weights from the point of view of BPA's DSM staff. To simplify the judgments from each staff member participating, the questionnaire only required the staff member to assign a weight

between zero and 100 to each impact. The results of the survey are presented in Table A-6. The survey questionnaire used is found in Appendix B.

The median response for each impact was used as the consensus of impact importance for this analysis. The consensus values associated with the specific impacts as shown in Table A-7 were normalized to proportionate weights that sum to 1.0. The weighted scores and the total weighted impact score for each measure were calculated as follows:

Impact	Relative Score	x	Weight	=	Weighted Score
Private industry	____	x	.116	=	_____
Private consumer	____	x	.130	=	_____
Government	____	x	.138	=	_____
Balance of payment	____	x	.071	=	_____
Employment	____	x	.138	=	_____
Resource materials	____	x	.130	=	_____
Quality of life	____	x	.116	=	_____
Environment	____	x	.161	=	_____
			Total Impact Score	=	_____

The total impact score will then sum to a value between 0 and 10.

Ranking

The actual ranking process is accomplished by combining the relative savings score and the total impact score as follows:

Ranking score = α (relative savings) + β (relative total impact score)

where α = importance of energy savings and

β = importance of impact

In this study, alpha and beta were both assumed to be 1. Thus, total impact was placed on a par with total energy saving. If the evaluators

TABLE A-6

EPA STAFF CONSENSUS FOR IMPACT WEIGHTS

Criteria	RESPONDENTS 1	2	3	4	5	6	7	8	9	10	11	12	Avg.	Median
A. Dollar Cost and/or Savings														
1. Total Impact	75	75	50	40	90	60	100	75	100	90	100	70	77	75.0
2. Public Sector	85	75	30	90	85	40	25	25	90	80	80	60	64	77.5
3. Private Consumer	90	75	50	90	70	70	90	50	95	90	25	60	71	72.5
4. Private Investor	80	25	40	60	60	50	25	50	75	90	80	60	58	60.0
5. Private Industry Development	70	30	50	80	75	60	50	25	80	70	80	70	62	65.0
6. Balance of Payments	60	20	30	30	80	10	10	25	70	60	60	50	42	40.0
B. Employment Effects														
1. Total Impact	80	60	60	90	95	65	90	75	80	70	100	70	78	77.5
2. Income Level	100	50	40	70	85	70	25	50	95	85	75	60	67	70.0
3. Geographic Region	80	75	30	80	70	60	90	50	95	100	50	50	68	65.0
C. Resource and Material Effects														
1. Fossil Fuels	90	75	70	80	90	45	10	75	95	90	50	100	73	77.5
2. Petrochemical Resources	70	50	50	50	80	35	40	90	90	50	75	80	63	55.0
3. Scarce Materials	85	25	90	90	85	40	50	50	95	70	75	70	69	72.5
D. Quality of Life														
1. Aesthetics	80	100	30	90	80	50	50	45	75	90	100	80	74	77.5
2. Comfort	80	50	70	20	70	60	25	10	75	95	75	40	56	65.0
3. Recreation	90	75	90	80	70	50	10	50	75	50	100	70	63	72.5
4. Cultural Changes	80	50	20	10	60	20	10	20	65	60	80	30	40	40.0
E. Environmental														
1. Air Pollution	90	90	90	90	85	70	90	75	90	90	100	100	88	90.0
2. Water Pollution	90	100	90	100	90	70	80	75	90	85	50	100	83	90.0
3. Solid Waste	75	50	80	80	80	65	50	50	90	50	50	100	68	70.0
4. Other Environmental Hazards	70	75	80	100	75	60	20	50	90	-	60	100	65	75.0
F. Technological Feasibility														
1. Primary Research	70	75	60	70	65	60	10	75	95	60	50	50	62	62.5
2. Development	90	50	60	60	60	55	100	50	95	90	50	50	68	60.0
G. Logistical Feasibility														
1. Siting Facilities	90	50	70	20	65	50	75	75	95	90	75	90	70	75.0
2. Material Distribution	70	50	50	60	60	40	75	25	85	80	100	40	61	60.0
3. Information Dissemination	50	25	30	70	55	30	25	25	85	60	50	30	45	40.0
H. Institutional Acceptability														
1. Political Feasibility	75	75	50	90	85	60	90	25	80	70	100	90	69	70.0
2. Legal Feasibility	75	40	70	20	80	25	20	25	80	80	50	50	46	50.0
3. Regulatory Enforceability	70	90	50	80	70	40	80	75	75	70	50	50	58	65.0
4. Acceptability	85	75	70	80	80	60	100	75	85	90	100	90	79	82.5
I. Qualitative Utility														
1. Attributable Factors	70	-	70	20	60	85	100	25	80	80	65	60	58	65.0
Average	78	55	55	64	74	51	53	50	84	73	75	67		

TABLE A-1

CALCULATION OF NORMALIZED WEIGHTS
FROM EPA STAFF CONSENSUS SCORES

MAJOR IMPACT CATEGORY	MEDIAN EPA STAFF SCORE	NORMALIZED VALUE 1/
Private industry	65.0	.116
Private consumer	72.5	.130
Government	77.5	.138
Balance of payment	40.0	.071
Employment	77.5	.138
Scarce resource	72.5	.130
Quality of life	65.0	.116
Environment	90.0	.161
TOTAL	560.0	1.000

1/ Normalized value = $\frac{\text{median staff impact score}}{560}$

desire impacts to affect ranking twice as much as energy savings then alpha would equal 1 and beta would equal 2, or:

Ranking score = 1 (savings) + 2 (impacts)

The measures are then ranked from highest to lowest.

APPENDIX I

QUESTIONNAIRE TO RATE CRITERIA FOR RANKING

PEAT, MARWICK, MITCHELL

DIRECTIONS

Peat, Marwick, Mitchell & Co. has been engaged by EPA to evaluate and rank various possible energy conservation measures. In order to evaluate the positive and negative impacts of the measures, it is necessary to establish criteria by which these measures can be judged. (An example of an energy conservation measure would be "to reduce use of packaging in the food industry by voluntary public participation and cooperation in coordination with FDA policy changes.")

PMM&Co. has listed below tentative criteria, grouped into categories, which could deal with both the effects of measures themselves and the means of implementing them. These criteria (or other similar ones) will be applied to each of the possible conservation measures to determine the best solutions in terms of impact as well as energy savings. We would like your help in establishing the relative importance of the various criteria to be applied.

Put yourself in the position of an administrator forced to make trade-offs among the effects of a measure on such different factors as employment, environment, the quality of life, and the measure's logistical feasibility. It is difficult to compare these factors, but how would you rate their impact on your decision among alternative measures?

Using a scale of 0 to 100, first rate each criteria <u>category</u> (on page 2), according to your view of its importance as a standard for judging energy conservation measures. For example, if you think that "Employment Effects" is a very important category in determining the ultimate impact of conservation measures, you might give that category a score of 90. On the other hand, if you think that employment effects are relatively unimportant compared to other categories, you might given that item only 10 points. Remember that the criteria may represent either positive or negative impacts (for instance, there may be an increase <u>or</u> a decrease in employment as a result of adoption of a measure), so think of the factors in general terms.

Rate each category on a scale of 0 to 100 points in importance--100 being the most important. Please use units of 5 in your rating (e.g., 5, 10, 15, etc.). It may help you to choose your "most important" and "least important" categories first, giving them the highest and lowest ratings, and then rate the other categories in between. Remember that a category given a "50" rating will be considered twice as important as one given a "25."

After you have rated each criteria category, please rate the individual <u>criteria</u> within each category (the numbered items), using the same procedure. Examples of the types of units used to evaluate each criteria have been included to help clarify the definition of the criterion.

Note that any number of categories and criteria may be rated "100" and any number may be rated "0." There is no limit on the total points within a category, and criteria within a category may be rated higher in importance

than the overall category itself. For example, you might give "Environment" a 60 rating as a category, but "Water Pollution" a 75 rating as a criterion.

TENTATIVE CRITERIA CATEGORIES

Category Rating

A. DOLLAR COST AND/OR SAVINGS
The importance of the overall cost or savings in dollars to various segments of the population. ___

B. EMPLOYMENT EFFECTS
The importance of an increase or decrease in employment for various income levels and geographical segments of the population. ___

C. RESOURCE AND MATERIALS EFFECTS
The importance of a scarcity of resources or materials in one area or the transfer from one scarce resource to another. ___

D. QUALITY OF LIFE
The importance of the positive and/or negative impact of a measure on those aspects of the nature of people's lives other than direct economic or employment aspects. ___

E. ENVIRONMENT
The importance of positive or negative effects on the environment, specifically increases or decreases in various types of pollution. ___

F. TECHNOLOGICAL FEASIBILITY
The importance of the need for additional research and development before a measure can be implemented. Technological feasibility might be measured in development years or probability of development. ___

G. LOGISTICAL FEASIBILITY
The importance of the availability of existing facilities and established processes and procedures for implementing a measure. ___

H. POLITICAL/LEGISLATIVE FEASIBILITY
The importance of a measure's ease of implementation in terms of its ability to be enacted through law or regulation and enforced. ___

I. CONTROVERSIALITY
The importance of acceptance and compliance with a measure by the general public as well as by specific affected segments. ___

TENTATIVE CRITERIA

I. EVALUATION OF THE EFFECTS OF MEASURES

Criteria Rating

A. DOLLAR COST AND/OR SAVINGS
The importance of the overall cost or savings in dollars to various segments of the population.

1. Total Impact - the total dollar cost or savings resulting from adoption of a particular measure. Total cost or savings might be measured by the dollars expended or dollars saved per year. ___

2. Public Sector - the dollar cost or savings to the taxpayers of a certain area resulting from adoption of a measure. This criterion might be measured in terms of dollars expended per capita within a jurisdiction (e.g., city, county, state). ___

3. Private Consumer - the dollar cost or savings to the consumer through adoption of a particular measure. Financial impact on the consumer might be measured in terms of increased dollar expense per consumer or percentage of income lost within different income classes due to that measure. ___

4. Private Investor - the dollar cost or savings to the investor upon adoption of a measure. Cost or savings to the investor might be measured in decline or increase in dividend rates per year. ___

5. Private Industry Segment - the dollar cost or savings to a certain industry segment upon adoption of a measure. Such a criterion might be measured by the dollars saved per unit output of the industry segment, or dollars expended for the measure per industry employee, or industry segment total opportunity costs. ___

6. Balance of Payments - the dollar cost or savings in terms of a measure's impact on the U.S. balance of payments. Dollar cost or savings in terms of balance of payments might be measured by dollar increase in importing or exporting. ___

Criteria Rating

B. EMPLOYMENT EFFECTS
The importance of an increase or decrease in employment for various income levels and geographical segments of the population.

1. Total Impact - an overall increase or decrease in jobs due to a particular conservation measure. This criterion might be measured by the number of new jobs created or the percentage change in unemployment.

2. Income Level - an increase or decrease in employment for different income levels resulting from adoption of a particular measure (e.g., are low income people affected more than higher levels?) Such a criterion might be measured by the change in available jobs within each income range or by the variation in the unemployment rate for different income ranges.

3. Geographical Region - an increase or decrease in employment for certain regions of the country due to a conservation measure (e.g., will the South experience an increase in jobs?) Impact on employment within a geographical region might be measured by the percentage increase or decrease in employment within different areas of the country.

	Criteria Rating
C. RESOURCE AND MATERIALS EFFECTS The importance of a scarcity of resources or materials in one area or the transfer from one scarce resource to another.	
1. Fossil Fuels - an increase or decrease in the scarcity of one or more fossil fuels (i.e., coal, oil, gas) resulting from a particular measure. This criterion might be measured by an increase or decrease in demand in terms of an arbitrary scale of the scarcity of fuel resources.	___
2. Petrochemical Resources - an increase or decrease in the scarcity of petrochemical resources due to adoption of a measure. Such a criterion might be measured by the quantity (in BTU's) of the resources affected.	___
3. Scarce Materials - an increase or decrease in the scarcity of materials already in low supply (e.g., copper and precious metals such as gold, silver, and platinum) due to a conservation measure. This criterion might be measured by the quantity (in BTU's) of the material affected or by an increase in annual demand as percentage of the known national reserves.	___

Criteria Rating

D. QUALITY OF LIFE

The importance of the positive and/or negative impact of a measure on those aspects of the nature of people's lives other than direct economic or employment aspects.

1. Mobility - an increase or decrease in the freedom to use vehicles for transportation (this could include availability of vehicles and financial feasibility of their use), resulting from adoption of a measure. This criterion might be measured by the amount of increased travel time for commuters or by decreased travel costs. ___

2. Comfort - an increase or decrease in the ease and convenience of everyday life due to a particular conservation measure. Such an increase or decrease might be measured by specific surveys, studies, or public opinion polls. ___

3. Recreation - a change in the choice of recreation activities and location due to a measure. This change might be measured by the percentage of time spent in recreation at home versus away from home or by the distance traveled for recreation. ___

4. Schedule Changes - an increase or decrease in the number of changes in work schedules and organized, scheduled leisure activities, (e.g. sporting and cultural events) resulting from a particular measure. The increase or decrease might be measured by surveys of corporation work schedules or surveys of cities for patterns of leisure activity schedule changes. ___

Criteria Rating

E. ENVIRONMENT
The importance of positive or negative effects on the environment, specifically increases or decreases in various types of pollution.

1. Air Pollution - an increase or decrease in the amount of air pollution (e.g., by carbon monoxide, hydrocarbons, sulfur dioxide, etc.) as a result of a particular measure. This criterion might be measured by the percentage of change in total emissions in critical (Priority I) areas of the County by specific pollutants. ___

2. Water Pollution - an increase or decrease in the amount of water pollution (by BOD, suspended solids, etc.) as a result of a particular measure. Such a criterion might be measured by the percentage of change in total effluence, in significant basins around the county, or in individual pollutants. ___

3. Solid Waste - as a result of a conservation measure, an increase or decrease in the amount of solid waste produced. This increase or decrease might be measured by a change in the quantity of waste or a change in cost per ton for disposal or a change in the amount of pollutant per ton of waste. ___

4. Other Environmental Hazards - an overall increase or decrease in pollution by other types of pollutants, such as noise, radiation, and toxic materials, due to adoption of a conservation measure. This criterion might be measured by the percentage of a change from existing levels of the pollution in specified areas. ___

II. EVALUATION OF IMPLEMENTATION OF MEASURES

Criteria Rating

F. TECHNOLOGICAL FEASIBILITY
The importance of the need for additional research and development before a measure can be implemented. Technological feasibility might be measured in development years or probability of development.

1. Primary Research - whether basic additional research will be necessary before a particular measure can be implemented. This criterion might be measured in terms of research time required (in years), funding or manpower required. ___

2. Development - whether additional technological development will be necessary before a particular measure can be implemented. This criterion might be measured in terms of development time required (in years), funding or manpower required. ___

	Criteria Rating
G. LOGISTICAL FEASIBILITY The importance of the availability of existing facilities and established processes and procedures for implementing a measure.	
1. Siting (Facilities) - whether new or additional facilities, renovation, or relocation will be necessary before a measure can be implemented. Such a criterion might be measured in terms of the time (in years) involved in carrying on the siting requirements, or the environmental effects of these siting requirements.	___
2. Materials Distribution - whether modified or additional processes and systems will have to be developed to distribute materials before a particular conservation measure can be implemented. This criteria might be measured in terms of time (in years) required to develop distribution processes or manpower necessary.	___
3. Information Dissemination - whether modified or additional processes and procedures will have to be developed to disseminate information before a particular measure can be implemented. This criteria might be measured in terms of manpower (both numbers and types of skills) required to develop dissemination procedures, or availability of information.	___

Criteria Rating

H. POLITICAL/LEGISLATIVE FEASIBILITY
The importance of a measure's ease of implementation in terms of its ability to be enacted through law or regulation and enforced.

1. Legislative Action - whether enactment of new legislation or regulations is necessary before a measure can be implemented. This criterion might be measured in terms of time required (in years) for the legislation to be enacted and the level of government (federal, state, local) required to pass the legislation. ___

2. Legal Precedents - whether there are previous legal precedents facilitating or hindering implementation of a measure. Such a criterion might be measured by subjective ranking of legal precedents. ___

3. Existing Governmental Structures - whether there are adequate existing governmental structures to implement and regulate a particular conservation measure. This criterion might be measured by subjective evaluation of the adequacy and necessary modifications to such structures or of the level (federal, state, local) at which modifications might have to be made. ___

4. Enforceability - whether the measure could be easily enforced once it was implemented. This criterion might be measured by the number and skill level of manpower required to enforce, or by additional facilities necessary to administer the enforcement. ___

	Criteria Rating
I. CONTROVERSIALITY The importance of acceptance and compliance with a measure by the general public as well as by specific affected segments.	
1. Attitudinal Factors - whether there are adverse or especially favorable attitudes toward a measure on the part of the general public or specific affected groups, such as labor or minorities. This criterion might be measured by voting records, polling results, or studies of affected sectors or groups.	___*

*No ranking since only one criteria is presented.

APPENDIX J

TECHNICAL DESCRIPTION OF HEAT PUMPS AND SOLAR ENERGY

MATHEMATICA

APPENDIX J

TECHNICAL DESCRIPTION OF HEAT PUMPS AND SOLAR ENERGY

1. USE OF SOLAR ENERGY AND/OR HEAT PUMPS

The potential for using solar/heat pump technology for residential use is currently one of the major considerations as part of the long term solution to the nation's dwindling fuel supplies. In this section of the study, the use of solar/heat pump technology as a conservation measure is analyzed, particularly for space heating applications. In making this analysis, it is important to consider the full range of technology for comfort heating:

- Air Source Heat Pump
- Full Solar
- Solar Assisted Systems

The use of solar energy to generate cooling is not considered to be a significant development for this time period. Absorption refrigeration units are available that can generate chilled water with 200°F water input as an energy source.[1] However, the efficiency of solar collection to provide this very hot water is very low. These improvements increase cost and technology improvements are required.

As shown in Figure J-1, house space conditioning and hot water are the most significant uses of energy and probably offer the greatest opportunity for conservation. Given the requirement for large amounts of thermal energy in the range 80-150°F for these uses, we need to examine the technologies likely to result in the best energy utilization given resources available. Two such technologies are heat pumps and solar energy.

The space conditioning system can be thought of as a converter - it takes high quality energy - electricity - and converts it to thermal energy. An electrical resistive heater produces 1 BTU of thermal energy for each BTU of electrical input, i.e. its coefficient of performance (COP)[2] is one. However, if we were to

---

[1] This section is based on a report prepared by Dr. H. L. Brown and Dr. B. B. Hamel for MATHEMATICA, Inc. (Brown and Hamel, 1974)

[2] The coefficient of performance of a heating system is defined as the ratio of heat energy produced by a system to the input energy.

FIGURE J-1

BASE ALL ELECTRIC HOUSE - HITTMAN

AVERAGE WEEK IN WINTER, AMBIENT AVG = 30°F, BTU/WEEK

	USER	ENERGY SUPPLIED	ENERGY DISCHARGED
	INCAND. LITES	122,000	109,000
	FLOUR. LITES	8,700	6,800
	SMALL MECH.	107,800	52,700
	SMALL THERMAL	18,000	16,900
	RANGE	98,000	93,800
	OVEN	29,700	29,700
	CLOTHES DRYER	226,000	223,500
	DISH WASHER	133,800	115,500
	CLOTHES WASHER (140°)	66,100	62,900
	HOT WATER SYSTEM (140°F)	519,900	519,900
	REFRIGERATOR (32°)	120,000	480,000
	HEATING SYSTEM (70°)	5,036,200	5,036,200
OUTSIDE TEMP	AVG (30°F)	30,000 BTU/HR	
OUTSIDE TEMP	PEAK (10°F)	52,000 BTU/HR	
	COOLING SYSTEM (70°) PEAK	35,000 BTU/HR.	

Source: Hittman

Reproduced from best available copy.

Use a heat pump we can obtain a COP of two by using one half BTU of electricity to obtain one BTU of thermal output. Some of the technical factors that limit heat pump performance are discussed in Appendix B. It is seen there that for air source heat pumps a COP of up to 2.5 is achievable, while water source heat pumps can give COPs of up to 4.0. Thus it can be seen that the use of an improved converter such as a heat pump allows the direct use of electricity as an end point fuel but with usage levels well below those encountered for resistive heat.

Solar energy is the use of an inexhaustible natural energy form available to the user directly in the form of low temperature energy. By the use of low temperature collectors (see Section 5) it is possible to make hot air or hot water directly available for space conditioning or hot water without any intermediate steps.

2. Technology of Solar Energy Utilization and Heat Pumps

a. Air Source Heat Pump

The heat pump is the best example of an efficient heating system. Heat pumps are electric or heat operated refrigerators or air conditioners operating in reverse. They warm the house by cooling the out-of-doors. The basic characteristics of the heat pump are described in Section 4. Mechanical energy, generally from electric motors, is used to bring in "free" but low temperature energy from the environment (outside air) and pump it up to warmer temperatures required for heating.[1]

For every BTU a heat pump consumes in electricity, it produces up to two in heating for a house. This compares with the one BTU of energy provided by electric resistance heaters for every BTU consumed in the house and approximately three BTU of fuel consumed at the electric power plant (assuming a 33% power plant efficiency). The use of the heat pump for space heating (and cooling when they are reversed) has to date been economically feasible only in the Southern regions of the country, but higher energy prices will make it economical in most regions of the nation[2]. A schematic comparison of the air source heat pump with an electric resistance system is shown in Figure J-2 . For the same source energy consumed, twice as much thermal energy is supplied by the air source heat pump compared with the resistive system.

b. Solar Assisted Systems

With the present state-of-the technology[3] and current energy prices, it is not easy to design an economically feasible space heating system with solar energy only; therefore, a significant step is the use of solar energy as assist or supplementary system. There are two basic systems which will be discussed under this heading.

---

[1] Hamel et al, 1972.

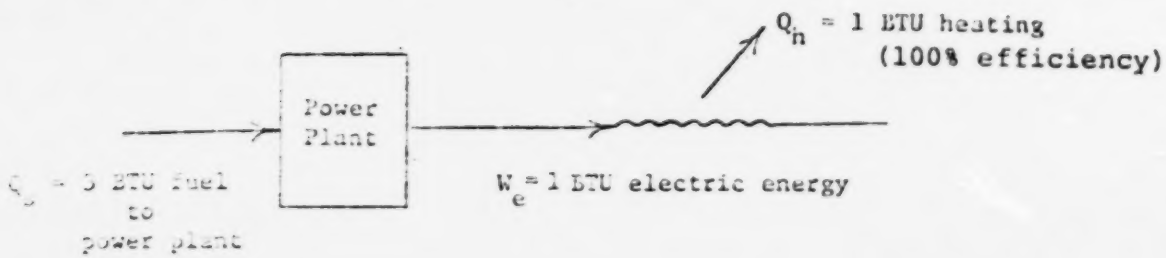
[2] Brown and Hamel, 1974.

[3] See, for example, NSF/NASA, 1972, University of Pennsylvania, 1973, University of Maryland, 1973, and IECEC, 1972-73.

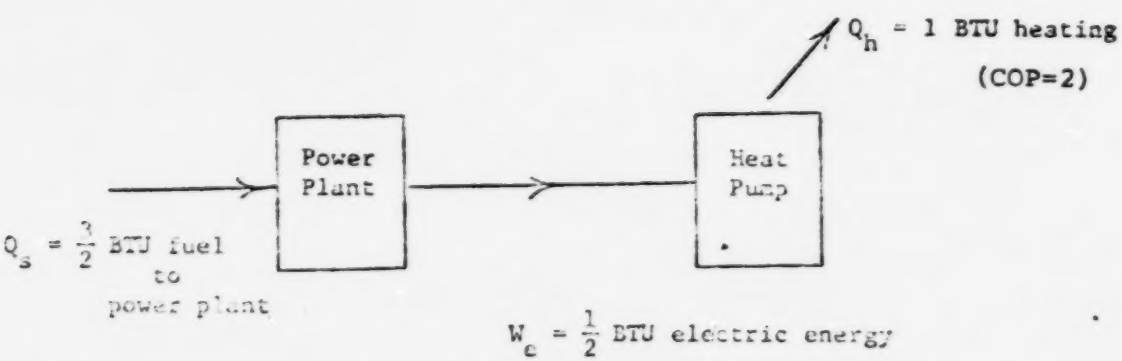
Figure 7-2

Comparison of Heat Pump with Resistive Electric Heating

Resistive System



Air Source Heat Pump



Thus,

Resistance: $\frac{Q_h}{Q_s} = \frac{1}{3}$

heat pump $\frac{Q_h}{Q_s} = \frac{2}{3}$

- Conventional Heating System with Solar Supplement[1]

In this system shown in Figure J-3a, the residence must have a conventional heating system, and the solar energy system is added to that conventional system to reduce fossil fuel or electric energy consumption. A description of the technology and operating characteristics of this system can be found in Section 4.

- Solar Assisted Water Source Heat Pump[1]

Another variation of the solar assisted systems is the solar assisted water source heat pump, Figure J-3b . In this concept, energy conservation is achieved through energy reclamation and solar energy. A detailed description can be found in Section 4.

As indicated in Section 4 this system can achieve a high performance with significant energy savings, particularly if the coefficient of performance is as high as 3 to 4.

- Full Solar

Residential dwellings may be heated and cooled with solar energy by use of some type of solar collector[3], such as the examples shown in Figure J-4 & Section 5. The possibility for solar cooling is limited[4] and will not be explored in depth due to the major research and development still required. A basic all solar system is shown in Figure J-5 . However, it is

---

[1] See Calvert, 1973.

[2] Brown and Hamel, 1974.

[3] NSF/NASA, 1972.

[4] See, for example, Swartman et al, 1973 and Thomason et al, 1974.

FIGURE 7-3a

Conventional Heating System with Solar Supplement

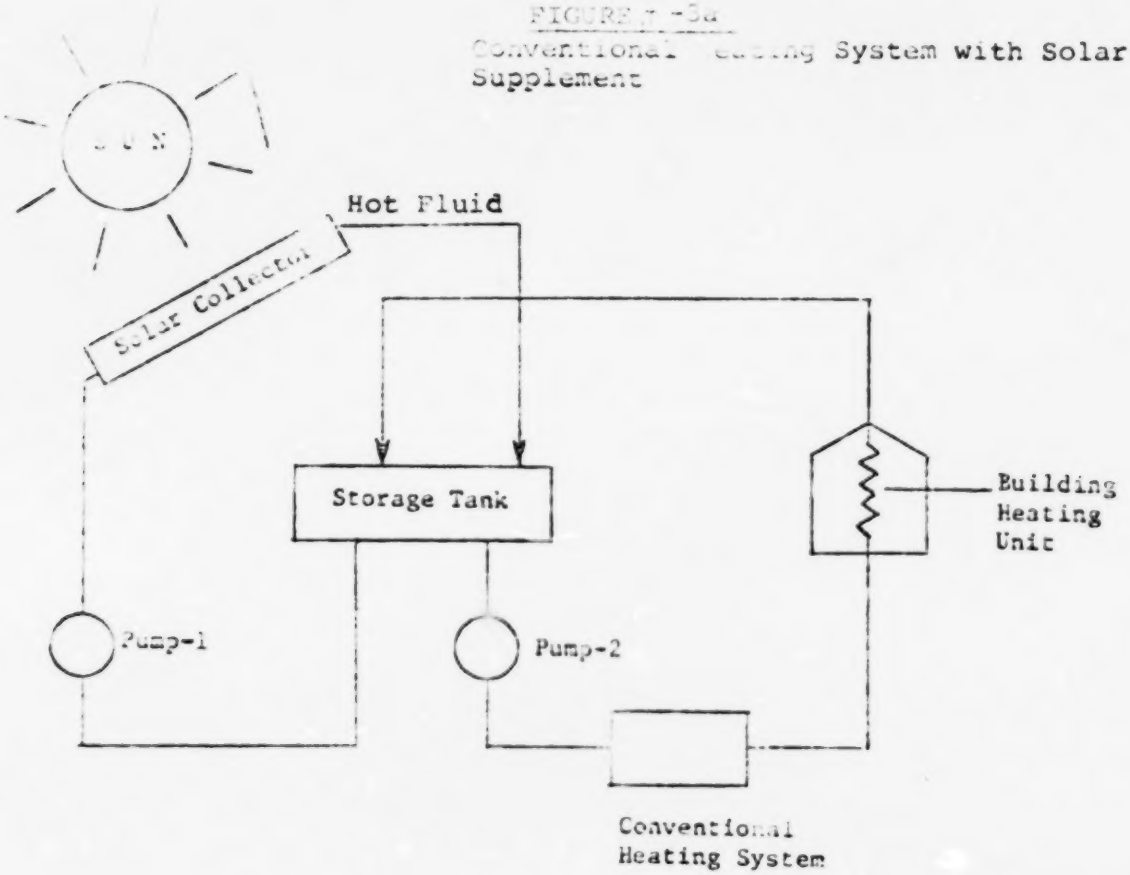


FIGURE 7-3b

Solar Assisted Water Source Heat Pump

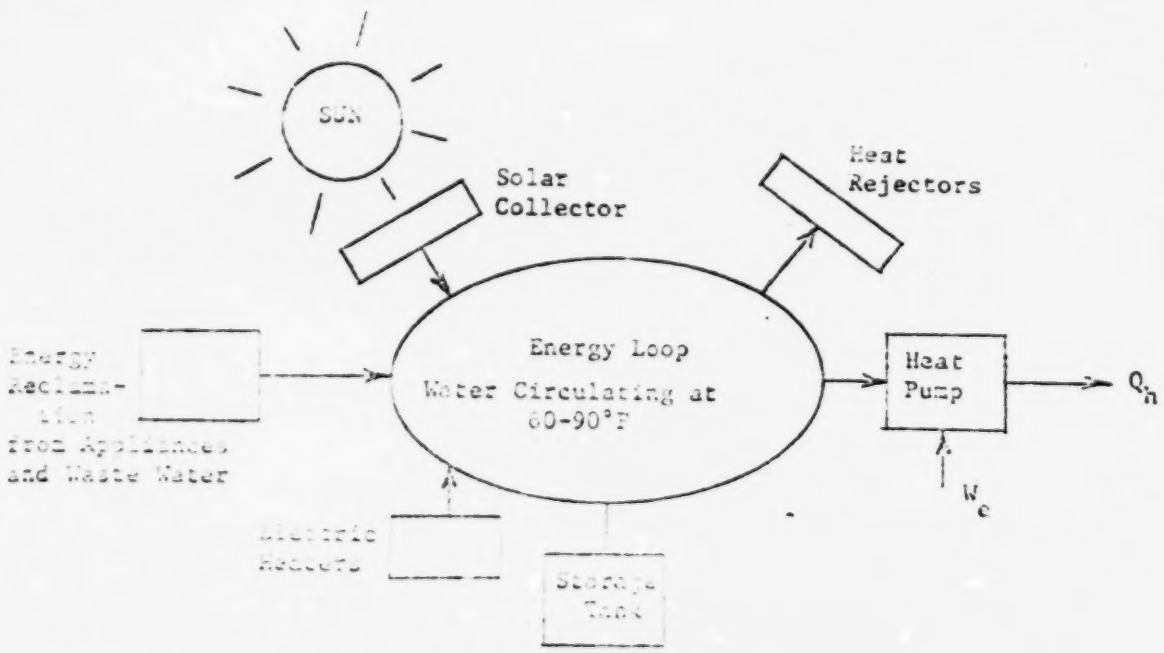
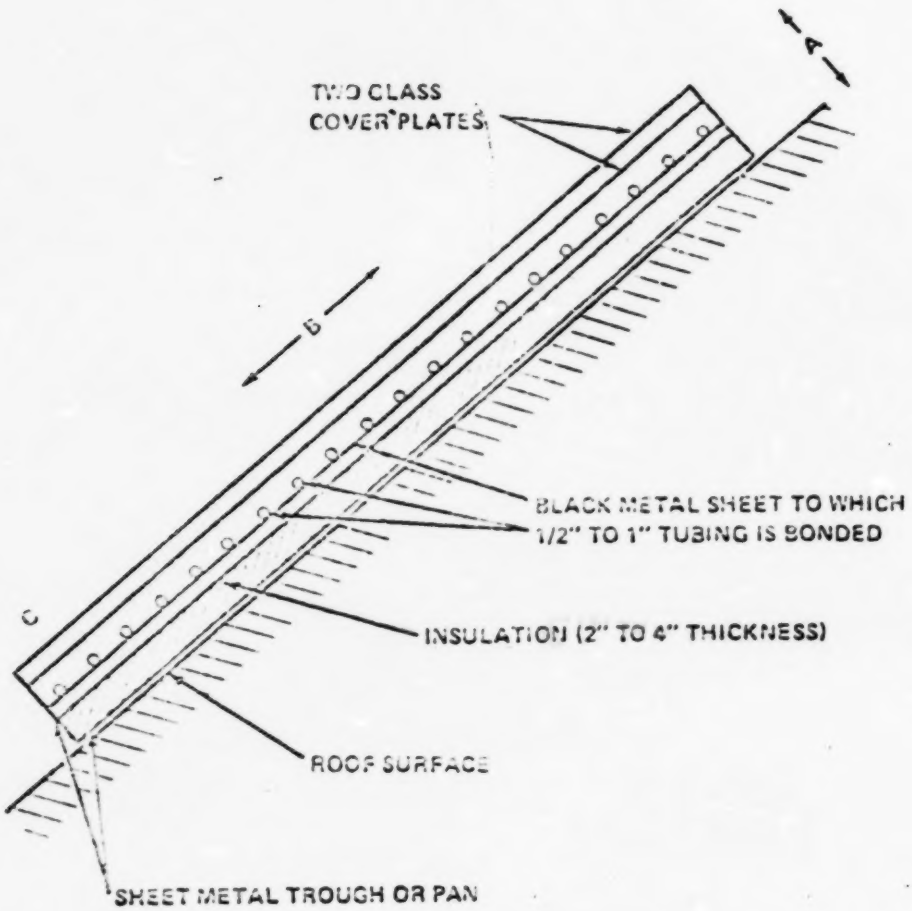


FIGURE J-1

SOLAR FLAT PLATE COLLECTOR FOR RESIDENTIAL HEATING
AND COOLING: DIAGRAMATIC SKETCH OF ONE ALTERNATIVE



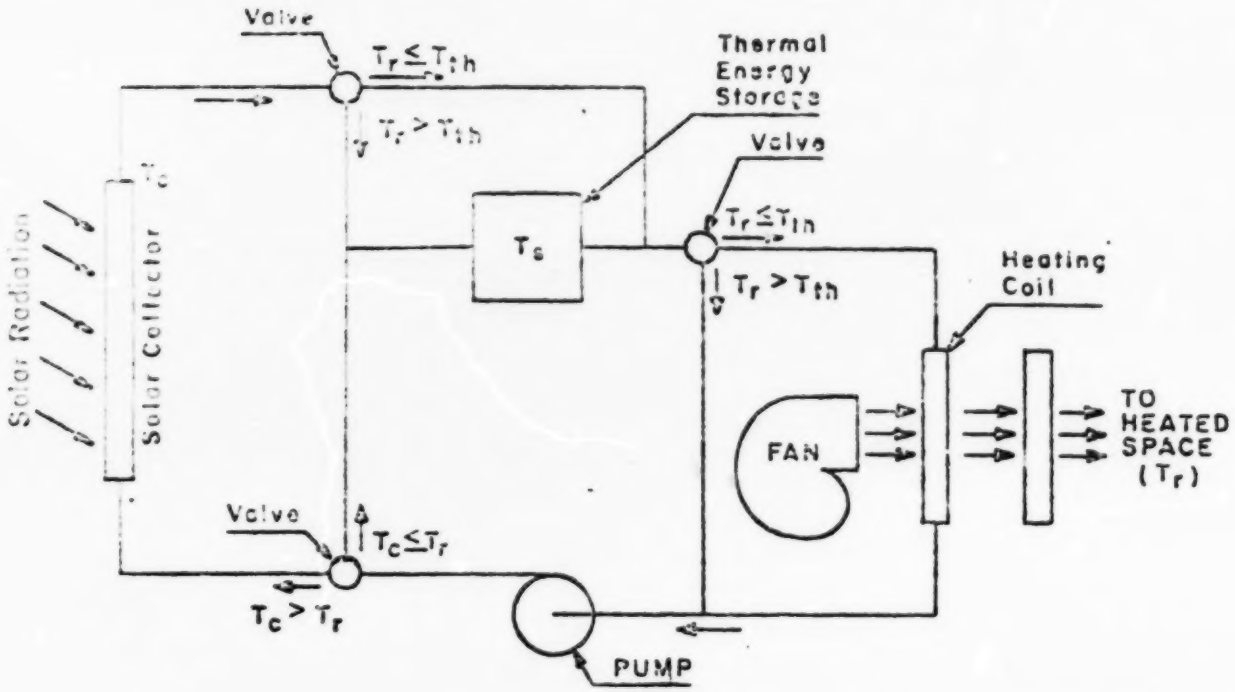
NOTES: ENDS OF TUBES MANIFOLDED TOGETHER
ONE TO THREE GLASS COVERS DEPENDING ON CONDITIONS

DIMENSIONS: THICKNESS (A DIRECTION) 3 INCHES TO 6 INCHES
LENGTH (B DIRECTION) 4 FEET TO 20 FEET
WIDTH (C DIRECTION) 10 FEET TO 50 FEET
SLOPE DEPENDENT ON LOCATION AND ON WINTER-SUMMER LOAD COMPARISON

Source: NSF/NASA - Solar Energy Panel, An Assessment of Solar Energy as a National Resource, December 1972.

FIGURE J-5

SOLAR HEATING AND THERMAL ENERGY STORAGE SYSTEM DIAGRAM



T_c = Collector temperature

T_r = Room temperature

T_s = Thermal energy storage temperature

T_{th} = Room thermostat setting

Fan Control: Same as for Conventional Heating System

Pump Control: On: $T_r < T_{th}$ and $T_c > T_r$

or: $T_r < T_{th}$ and $T_s > T_r$.

or: $T_c > T_s$

Source: University of Pennsylvania, "Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating", July 31, 1973, and Brown, H. L. and Hammel, B.B., Solar/Heat Pump Systems as Energy Conservation Measures, Report submitted to MATHEMATICA, Inc., August 1974.

evident that such systems need a back up or auxiliary system - even if it is full solar - and therefore such an auxiliary is usually designed into the building.

There are other variations but these type system layouts are generally consistent with most concepts. The two major components are:

° solar collector

° thermal storage system

As a result of needing higher temperature for heating directly, the efficiency drops (See Section 5) and the cost increases. In addition if it is designed to operate fully on solar, the storage element must be a significant component for design and cost.

Over 20 experimental solar heated structures have been designed, built and operated. Some of these are listed in Section 5. Workable heating systems have evolved from these experiments. However, they are not all fully engineered, both from the point of view of selecting the best systems or optimizing the design of those systems. Solar collectors, energy storage elements and heat transfer systems are in a relatively early stage of component development and engineering.[1] Technical feasibility appears assured; however, economic feasibility has yet to be demonstrated. Significant research and development is required to reduce cost and develop significantly improved and engineered systems.

3. Energy Savings and Economics

In this section the discussion focuses on the possible roles that the heat pump and solar energy systems will play in the residential sector. Conservation options are identified in general for the house and the heat pump and solar options are

---

[1] University of Pennsylvania, 1973, 1974, NSF/NASA, 1972, and Swartman et al, 1973.

the use of an improved converter such as a heat pump allows the direct use of electricity as an end point fuel but with usage levels well below those encountered for resistive heat.

- solar energy:

The second direction for conservation is the use of natural energy forms available to the user directly in the form of low temperature energy. Solar energy is such an energy form. By the use of low temperature collectors (see Section 5) it is possible to make hot air or hot water directly available for space conditioning or hot water without any intermediate steps.

- waste energy recovery:

The third opportunity for conservation is the recovery of waste energy in the house. It is evident from Figure J-1 that the waste energy available in the house can account for as much as 10-15% of the hot water/space conditioning requirement.

A system configuration using the heat pump, solar energy and waste energy can therefore be an important energy conservation measure.

b. System Configuration and Energy Savings and Economics

There are three basic systems that utilize heat pump and solar technology. The basic advantages and disadvantages are discussed and a comparison made on the basis of energy savings and economics as follows:

- Air Source Heat Pump:

Basic characteristics of the air source heat pump are described in Section 4 . As the ambient temperature decreases the COP of the heat pump decreases, so that for regions further north the heat pump performance deteriorates: a typical COP for Atlanta can be 2.2, while for Philadelphia it will be 1.6 and Minneapolis 1.3. In general the cost of

examined in this broader context. The possible system configurations are indicated and an evaluation of energy savings and economics is presented.

a. Uses of Energy in the House and Directions for Conservation

In order to see the conservation options in perspective, we show in Figure J-1 a rather inclusive list of energy uses in the house. In the figure is shown the amount of energy required, the energy discharged (or wasted) and the approximate temperature at which the energy is required (if thermal).

In examining Figure J-1 the most striking comment we can make is that house space conditioning and hot water are the most significant uses of energy and probably offer the greatest opportunity for conservation. Given the requirement for large amounts of thermal energy in the range 80-150°F for space conditioning and hot water, we need to examine the technologies likely to result in the best energy utilization given the resources available.

In examining the data in Figure J-1, three general recommendations can be made for improved energy utilization:

- improved converter performance:

If the space conditioning system can be thought of as a converter - it takes high quality energy - electricity - and converts it to thermal energy. An electrical resistive heater produces 1 BTU of thermal energy for each BTU of electrical input, i.e. its coefficient of performance (COP) is one. However, if we were to use a heat pump we can obtain a COP of two by using one half BTU of electricity to obtain one BTU of thermal output. Some of the technical factors that limit heat pump performance are discussed in Section 4 . It is seen there that for air source heat pumps a COP of up to 2.6 is achievable, while water source heat pumps can give COPs of up to 4.0. To summarize,

of the heat pump will be about 10% greater than an air conditioner of comparable size, as additional controls are required. So that a house with electrical resistive baseboard units and central air conditioning will have a first cost that is 10% less than the ASHP. Operating costs and energy savings, compared to resistive heat will be given by the relation: $(1 - \frac{1}{COP})$ as the percentage savings. These estimates are detailed in Figure J-6.

° Solar Assist/Hybrid Systems

Both solar technology and heat pump technology have their own unique problems. The main difficulty suffered by solar technology is economic: if one attempts to provide all thermal requirements by solar energy the first cost becomes very high. The range of possible systems in this class is wide and may include:

- resistive heat with solar assist
- fossil fuel heat with solar assist
- conventional heating with solar domestic hot water
- solar assisted heat pump

Among these, the two that seem most promising are conventional heating with solar domestic hot water, and solar assisted heat pump. The former will be of considerable interest in southern areas where insolation is favorable. Its use involves a modest first cost: $450 - $900, depending on solar panel costs and involves perhaps 80-100 ft^2 of solar panel area. Commercial availability of units can be expected in the immediate future.

The second option seems to offer the best prospect for a solar assist system for space conditioning as well as hot water. Here, the solar energy that is collected is used to raise the temperature from which the heat pump takes energy. By using a water source heat pump, higher COPs can be achieved due to better heat transfer. Because solar energy is used, not to directly space condition, but to energize the heat

pump, it may be collected at 90-100°F rather than 135-150°F. This allows significantly higher collection efficiencies (See Section 5), and therefore less solar area per BTU collected. In addition, the water loop system allows one to collect the waste energy available in the house. In general this system is of some interest because it seems possible here to overcome the deficiencies of the solar and heat pump systems with this hybrid and can lead to savings of as much as 60% of the space heating energy.

° Full Solar

A full solar system will in general invelve the low temperature collection of solar energy (150°F) in flat plate collectors located on the roof. The fluid that circulates through these collectors will then communicate with a basement storage system and from this system either a hot water or hot air loop will provide space conditioning. In general, four days of winter storage will be necessary and a backup electrical resistive heater will be required as an insurance measure.

A discussion of the design considerations and economics of a full solar system is given in Section 5 . A summary of the economics and energy savings is given in Figure J-6 .

c. Calculation of Energy Savings

Since electricity will likely be the main source of energy in new construction in the future, the air source heat pump offers the best prospect for an immediate 30% saving in energy with first cost increases that are modest.

Solar hot water heating is probably now practical in Florida and California, and we can expect practical commercial systems in the near future.

Solar assisted space conditioning is promising, especially solar assist water source heat pumps. However, significant development and field testing are required.

FIGURE J

ENERGY SAVINGS IN SPACE HEATING APPLICATIONS

(RELATIVE TO RESISTIVE SYSTEMS)

	SYSTEM	% Savings
1)	Air Source HP	30
2)	Solar Assist	60
3)	Full Solar	95

Source: Brown, H.L. and Hamel, B.B., "Solar Heat Pumps", report to MATHEMATICA, Inc., August 1974.

The economics of these systems look promising: amortized $/MBTU costs are competitive with fossil fuel costs and incremental first costs are not excessive.

Based on Brown and Hamel (1974), the following assumptions have been made for maximum rate of implementation of the three types of systems over the time period considered in this study.

	Applied to	1977	1980	1985	1990
a. ASHP	New electrically heated homes	5%	10%	20%	35%
b. Solar Assisted Systems	All new homes	0	2%	6%	15%
c. All Solar	All new homes	0	0	3%	10%

4. HEAT PUMP CHARACTERISTICS

In the technical literature the term "reverse cycle heat pump" usually carries the connotation that the ultimate objectives of such systems are to provide thermal comfort for winter requirements and cooling effects in summer (air conditioning). In Figure J-7, an air source (air-to-air) heat pump is shown. Air from outdoor enters a circulating fan (at lower left-top sketch) the outdoor air is blown over the finned evaporator coils and gives up energy at low temperature to the refrigerant passing through the evaporator. It is apparent that the air discharged from the evaporator must be colder than the outdoor supply air. The high-temperature and high pressure vapors discharged from the refrigerant compressor pass through the condensor, where the cool return air from the various rooms of the house is heated by the condensing refrigerant. Warm air leaving the condenser then passes through the rooms of the building and helps to maintain the desired indoor temperature. The measure of performance for the heat pump system is defined as follows:

$$\text{Coefficient of Performance (COP)} = \frac{Q_h}{W_e}$$

in which Q_h is the heat delivered at the condenser to indoor air and W_e represents all of the electrical energy input to the system. For the ideal (Carnot) heat pump, the maximum COP is defined by the Second Law of Thermodynamics, as follows:

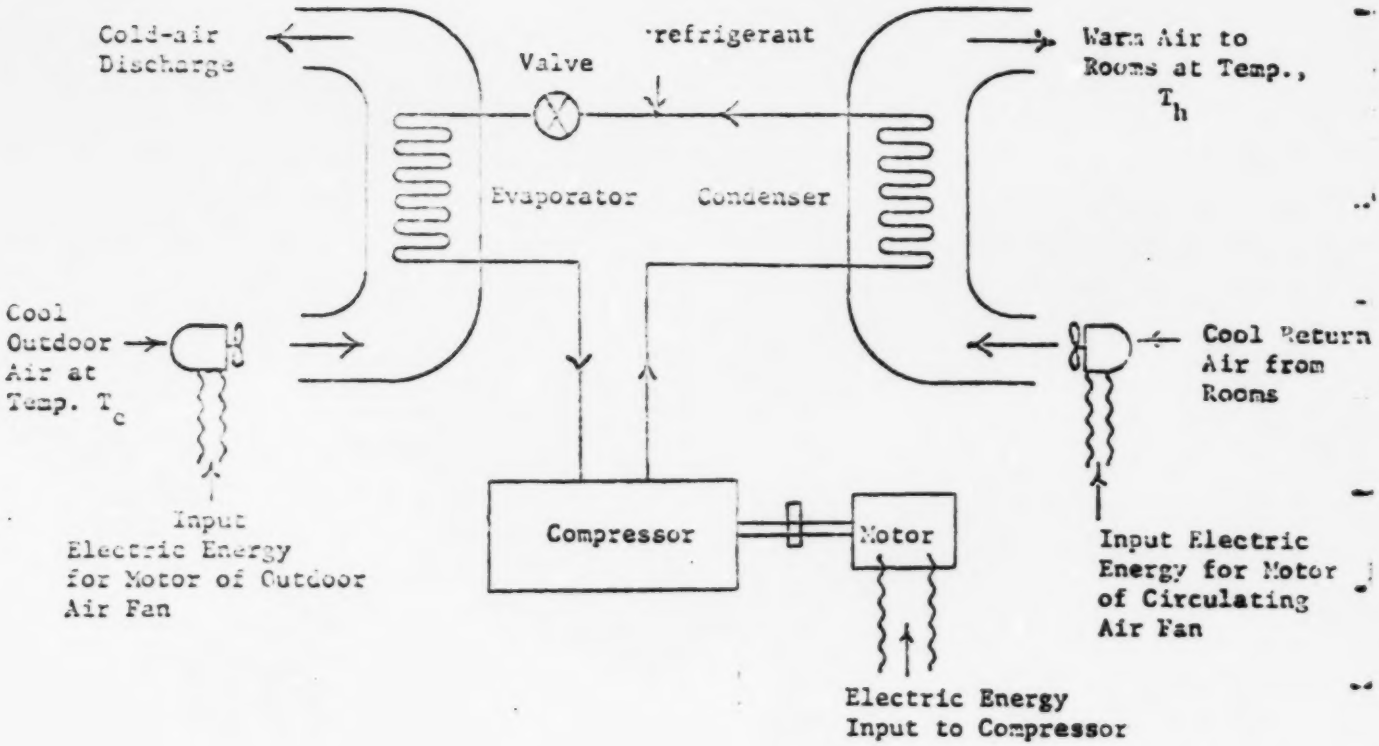
$$COP_{\text{ideal-Carnot}} = \frac{T_h}{T_h - T_c}$$

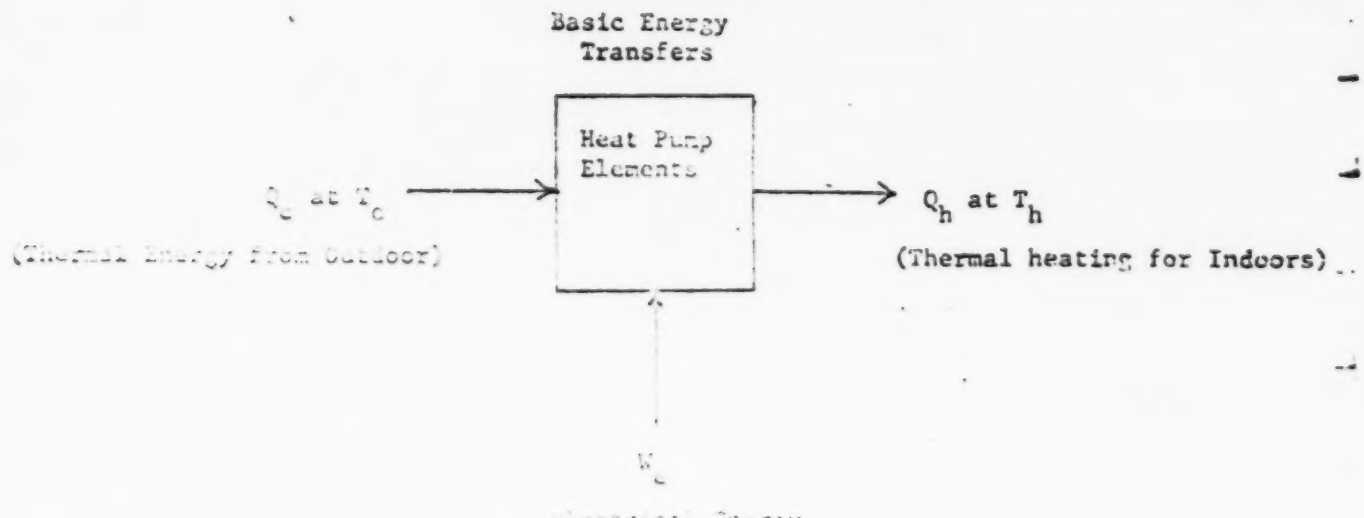
where the temperatures are given in absolute values.

FIGURE 5-7

Basic Elements of

Heat Pump System





T_c = temperature of outdoor air

T_h = temperature of indoor air

Modern heat pump systems (as shown in Figure B-8), when they are operating at optimal output and under mild climatic conditions, attain approximately 10 to 20 per cent of their limiting theoretical efficiency. Under more severe climatic conditions, where the actual coefficient of performance drops off, the efficiency of the heat pump system attains 5 to 10 per cent of the limiting value. The heat pump itself, however, is not an especially inefficient machine. If one examines the performance of the overall heat pump system, one finds that the largest irreversibility responsible for the largest loss of thermodynamic availability in the whole heat-pump system, is the air distribution system. The principal cause of inefficiency in this system is that with conventional air ducts and fans, in order to keep a room at 70°F, it is necessary to supply air to the ducts at 110°F to 130°F. This, of course, considerably reduces the overall efficiency of the heat pump system. Thus overall examination of Figure J-8 indicates that the temperature drops across the heat exchanger surfaces within the air distribution system account for the major losses and the largest drop in COP.

The performance curve for a carrier three ton unit is shown in Figure J-9. It is apparent that as the outdoor temperature increases to 45° - 50°F the COP increases to a maximum. Thus, as indicated earlier, air source heat pump performance in the warmer section of the country is significantly better than in the cooler region.

To establish the COP of a water source heat pump at design temperature, the Ambrose Loss Factors for Air Source heat pumps in Figure J - 8 may be used. For a given temperature ratio for which the heat pump is to operate, a set of factors that reduce the COP from the Carnot value to the value attainable for a real heat pump are established. The Ambrose Loss Factors are modified for the change in temperature drop on the source side of a water source heat pump.

If a water source heat pump system were considered and the water source were maintained at 60 to 80°F, the COP approaches 3.0 to 3.2.

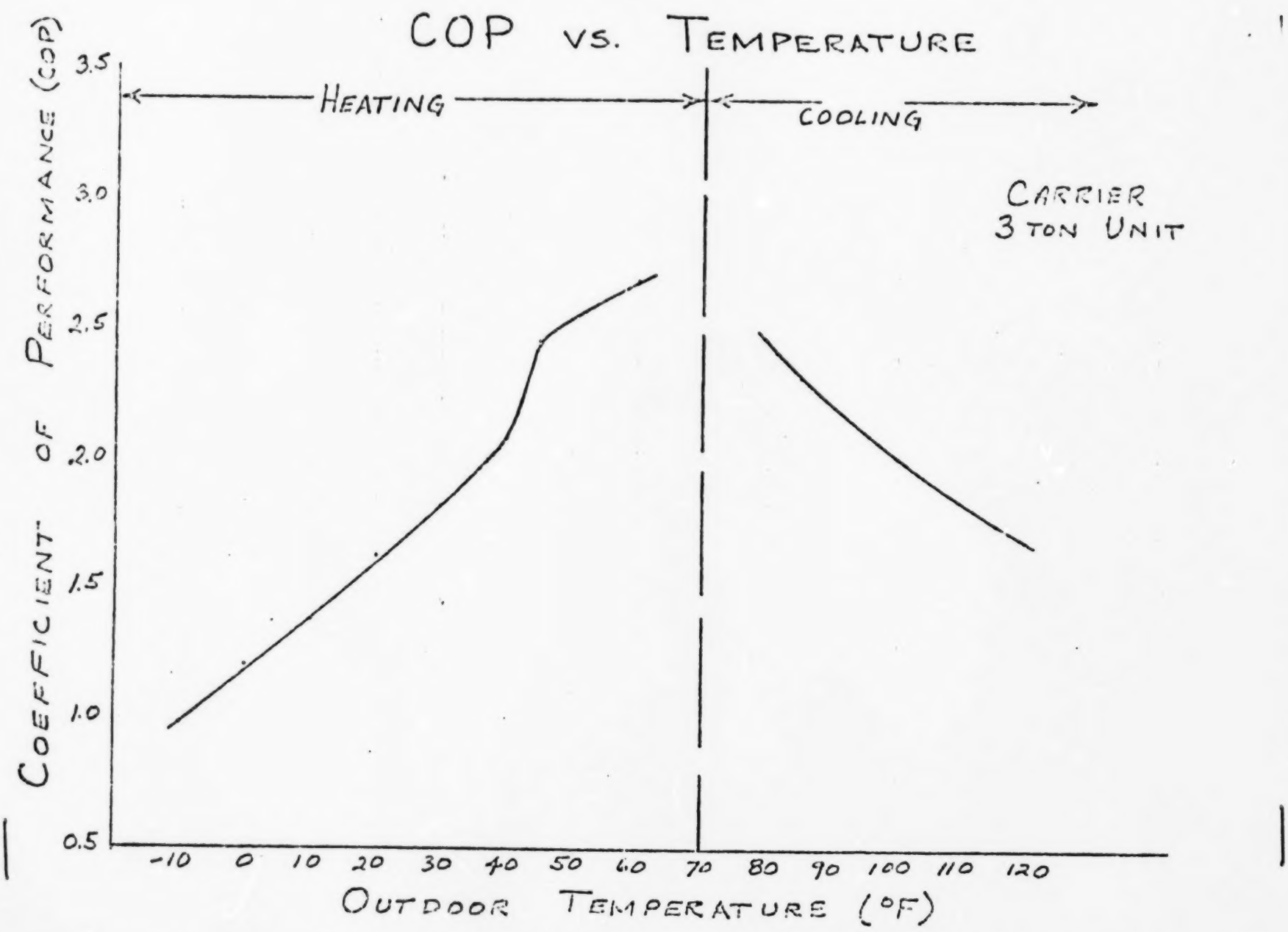
FIGURE J-8

PERFORMANCE OF HEAT PUMP

AMBROSE LOSS FACTORS

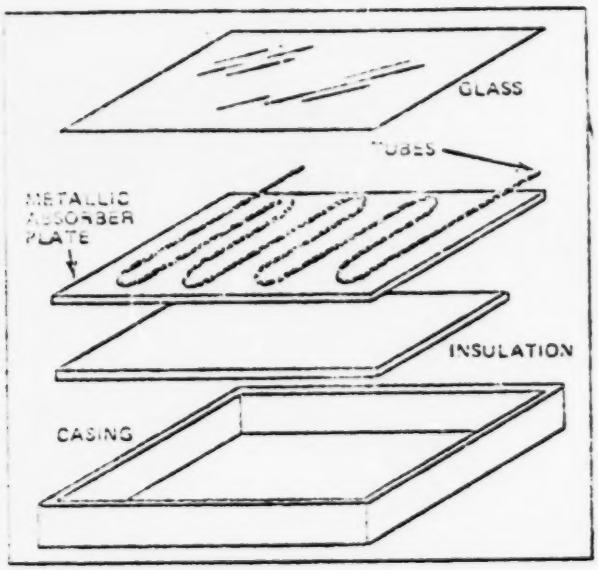
FUNCTION OF COP FROM IDEAL CARNOT SYSTEM	COEFFICIENT OF PERFORMANCE (COP)	HEAT SINK TEMPERATURE (EVAPORATOR)	HEAT SOURCE TEMPERATURE (CONDENSER)	CONDENSER TEMPERATURE	EVAPORATOR TEMPERATURE	ASSUMED DESIGN AND OPERATING DEVIATIONS FROM THE CARNOT CYCLE (DURING HEATING CYCLE)
% RATIO		°F	°F	°F	°F	
100	21.2	70	45	-	-	CARNOT CYCLE
59.4	8.6	70	45	100	35	NO. TEMP. GRADIENT BETWEEN HEAT TRANSFER SURFACE & HEAT SOURCE-SINK
7.2	7.1	70	45	105	25	TEMP. GRADIENT BETWEEN REFRIG. & HEAT TRANSFER SURFACES
13.6	4.2	70	45	105	25	REQD. FAN POWER FOR FORCED CONVECTION OVER HEAT SOURCE-SINK TRANSFER SURFACE
0.8	4.0	70	45	110	20	PRES. DROP WITH CORRES. SAT. REFRIG. TEMP. CHANGE DUE TO REFRIG. FLOW THROUGH PIPE, VALVES, ETC.
2.5	3.5	70	45	110	20	DEPARTURE FROM IDEAL COMPRES. CYCLE COMPRES. NOT 100% EFFICIENT
2.1	3.0	70	45	110	20	80-90% EFF. COMPRESS. - MOTOR COMB. HERMETICALLY SEALED MOTOR LOSSES ADDED TO REFRIG. BEFORE COMPRESS.
2.1	2.6	70	45	110	20	MISC. LOSSES CAUSED BY FROSTING & DEFROST. OF HEAT SOURCE COILS, CONTROLS, ELEC. EQUIP., ETC.
12.3	2.6	70	45	110	20	RESULTANT PERFORMANCE OF TYPICAL SMALL UNITARY HEAT PUMP UNIT

FIGURE J-9


COP vs. TEMPERATURE
HEATING
COOLING
CARRIER
3 TON UNIT
COEFFICIENT OF PERFORMANCE (COP)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
OUTDOOR TEMPERATURE (°F)

5. SOLAR COLLECTOR TECHNOLOGY

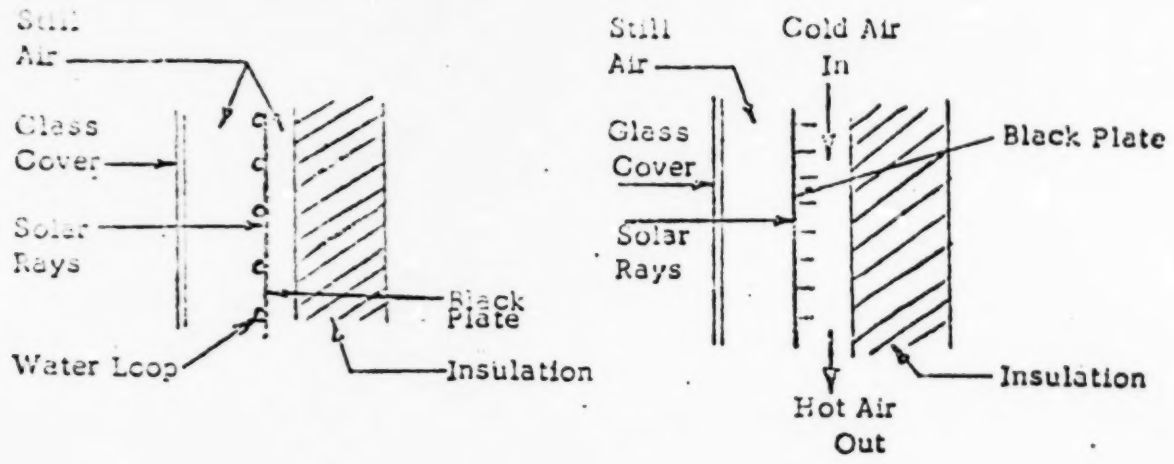
Most of the solar space-heating applications completed to date are generally of a stationary, non-focusing flat plate collector type. The basic elements of this type collector are shown below:

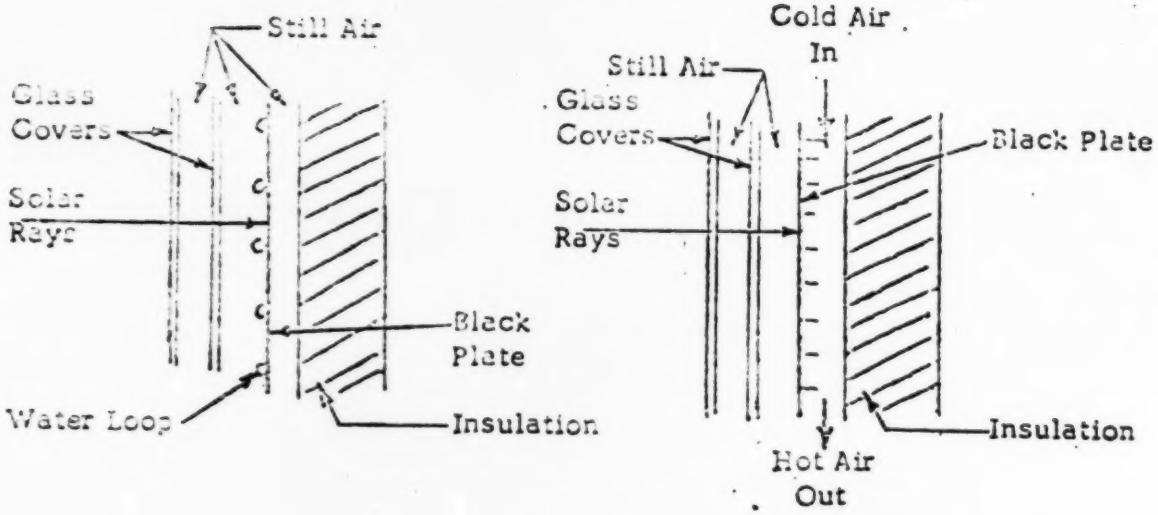


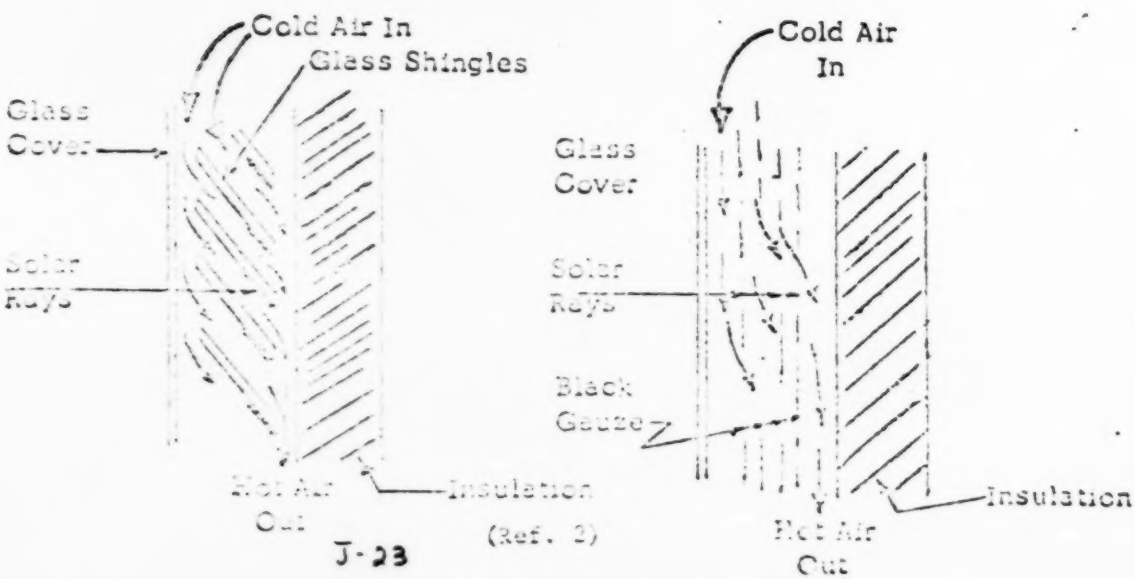
When these elements are combined together, a "green-house" effect is created where the flowing fluid in the tubes is heated. Although these are the basic components there are many variations to these elements as shown in Figure J-10. The more complex the system the more costly the collector.

The basic collector consists of a metal plate which is painted black on the side receiving the solar energy and insulated on the edges and back side. Above the metal plate, there are usually one, two or three glass or plastic plates to reduce heat loss. Solar energy passes with little absorption or reflection through the glass plates and is absorbed by the black plate which is then heated. Part of the energy absorbed will be lost by radiation and convection through the air

FIGURE J-10

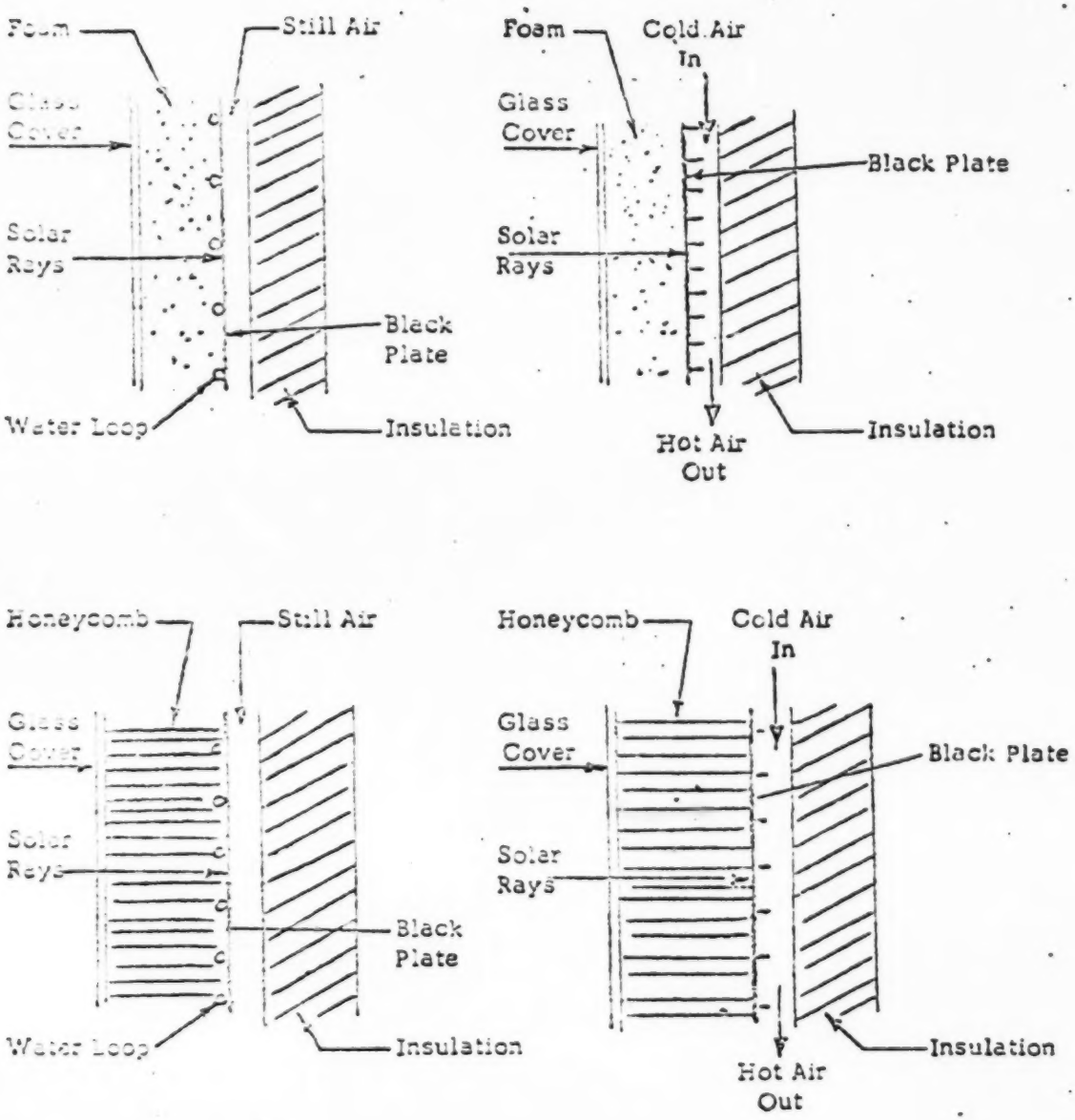






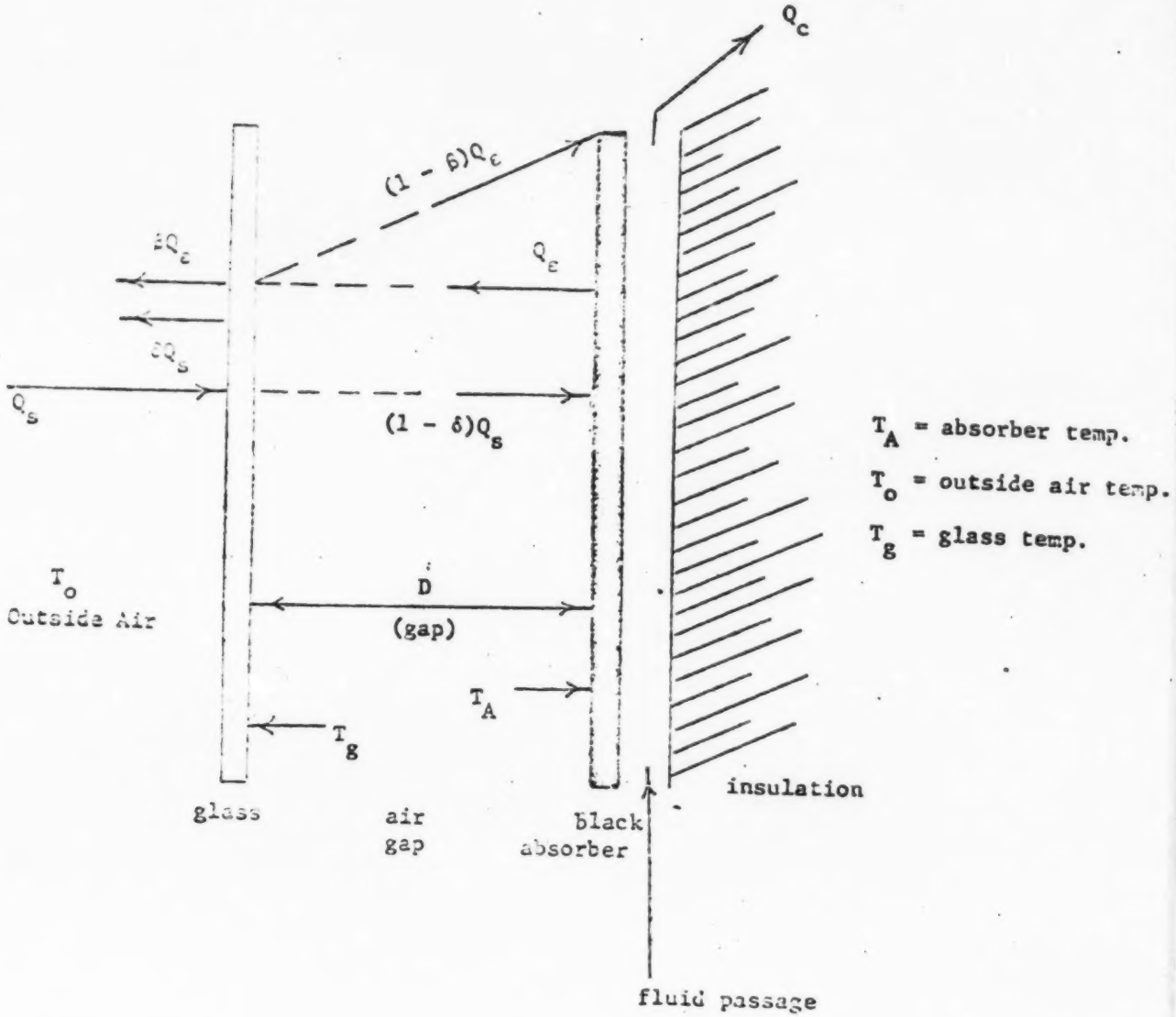
(Ref. 2)

FIGURE J-10 (continued)



gap. The heat is available to be transferred by the fluid flowing in the tube which is mounted on or within the collector plate.

Given this basic description and given the incident solar radiation on a flat plate collector, the question then is: how much of this incident energy can be collected? Below is a simplified sketch of a single plate, flat plate collector with energy transfers to illustrate the mechanics of collection.



Where

Q_s is the incident solar energy.

Q_ε is the radiant energy from the black absorber.

δQ_s is the small amount of incident solar absorbed in front glass plate which is then lost to environment.

δQ_g is the small amount of radiant energy which passes through the front glass

Q_c is the energy content of flowing fluid which has been heated up.

From these basic terms, the following has been developed as the collector efficiency:

$$\eta = \frac{Q_c}{Q_s}$$

which is the ratio of energy collected to incident solar energy. If this analysis is carried through in detail the following first approximation correlation is developed:

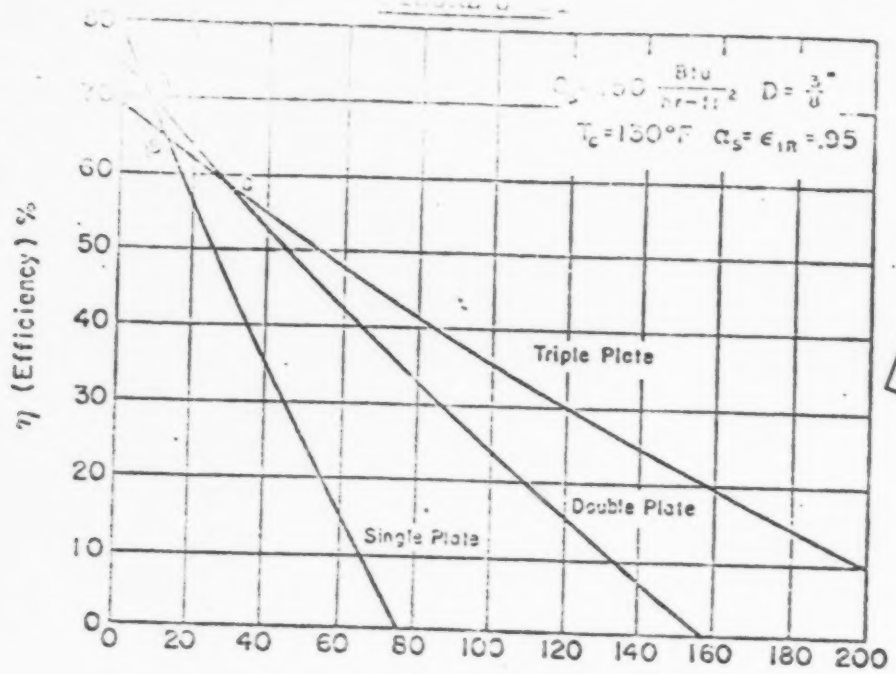
$$\eta = a + \frac{bT^4_g}{Q_s} + \frac{cT^4_A}{Q_s} + d\,\frac{\Delta T}{Q_s}$$

where

$$\Delta T = T_A - T_o$$

and a, b, c and d are determined from design parameters. The efficiency versus ΔT for various type designs (single, double, triple plate) are shown in Figure J-11.

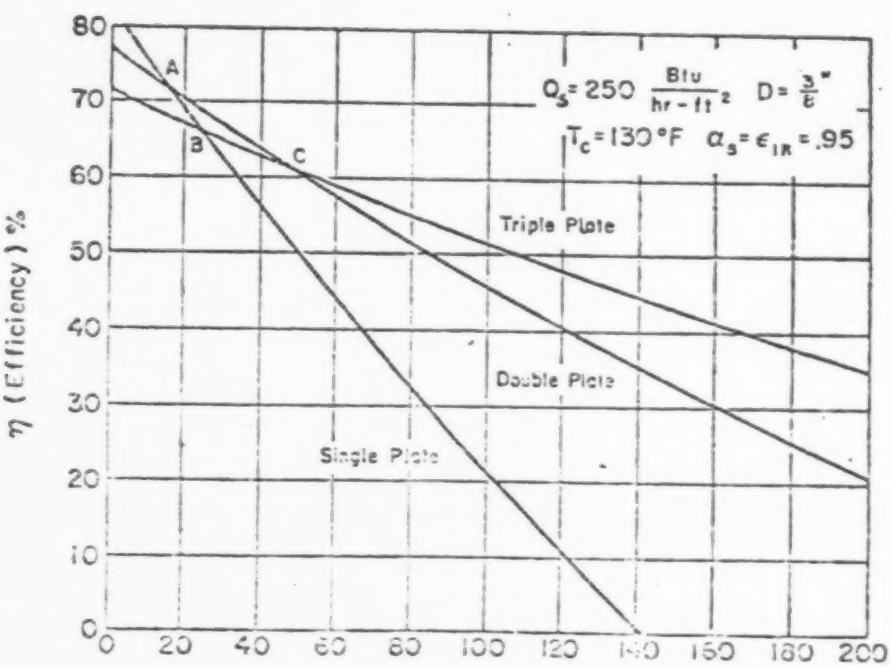
As shown the efficiency drops off sharply with decreasing Q_s and for increasing ΔT. Therefore, the prime time to collect solar energy is during the heat of the day and while collecting at relatively low temperatures (T_A) ~ 60°F to 100°F. As T_A increases, ΔT increases for any given outside temperature, T_o.



Reproduced from best available copy.

$\Delta T = T_A - T_o$ (°F)

Effect of Number of Glass Plates on Collector Efficiency for Low Insolation.



$\Delta T = T_A - T_o$ (°F)

Effect of Number of Glass Plates on Collector Efficiency for High Insolation. (Ref. 2)

Thus the energy loop heat pump system operating between 60°F and 80°F, may experience a solar collection efficiency of 40 to 60% whereas if the solar energy is collected from 120°F to 160°F, the efficiency might drop to 5-10% for a single plate collector. Thus, if collection is to be done at higher temperatures, double plates and other features are necessary and increased costs result.

Certain developed absorbent surfaces, called selective surfaces, can improve efficiency of the collector by more than 10% compared to the plain flat-black paint. Ordinary window glass has transmittance of 85% but it is possible to improve this. Although the basic flat plate collector discussed is a proven product, the objective of current research and development is to increase efficiency and reduce cost. Since the flat plate collectors absorb solar radiation, such systems are designed with the collectors installed at angles ranging from completely horizontal to vertical. However, a rule of thumb for maximum energy collection, the solar panels should be installed at angles equal to: 10 degrees plus the latitude of the location for heating application and equal to the latitude of the location for dual heating and cooling. A change of 10 degrees plus or minus, does not create any appreciable change.

Similarly, orientation of solar panels facing due south is most desirable, but orientation of 45 degrees from the south in an easterly or weterly direction is not a major factor in reducing solar collection.

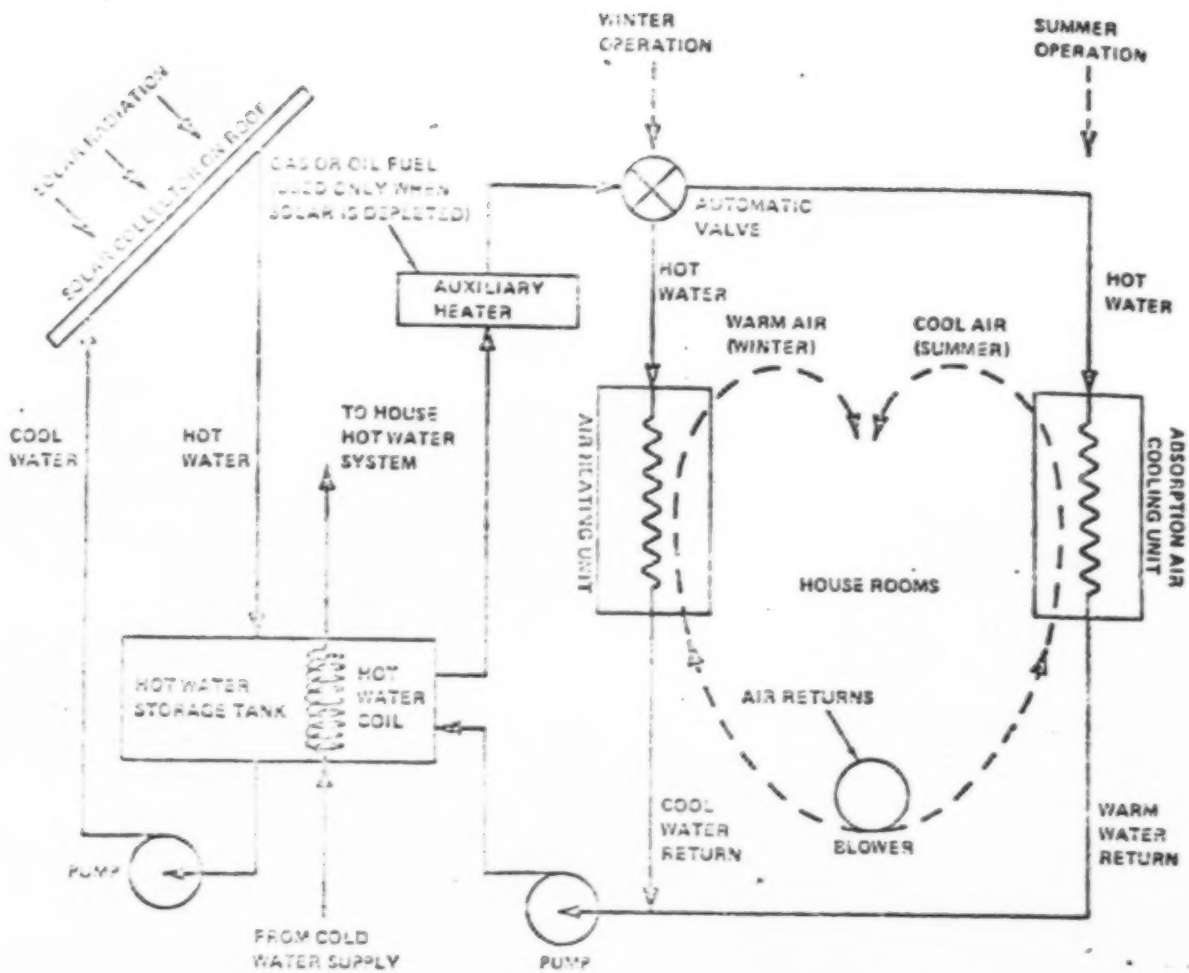
A pragmatic diagram of a typical residential application is shown in Figure J-12.

A summary of solar houses and buildings are shown in Figure J-13. These systems range from solar assists to full solar systems. In recent years additional solar houses and buildings have been constructed which are not shown on the list, including many at universities and demonstration facilities for government and industry.

FIGURE [illegible]

RESIDENTIAL HEATING AND COOLING WITH SOLAR ENERGY:

SCHEMATIC DIAGRAM OF ONE ALTERNATIVE



(Ref. 2)

FIGURE J -13

SUMMARY OF PREVIOUS EFFORTS IN SOLAR HEAT UTILIZATION IN HOUSING (Ref. 2)

No.	Year	House, Location	House Heat Req. ft.², Type	Solar Collector Surface Area, Type	Auxiliary Energy Storage	Loops: Coil to Storage	Loops: Storage to Space
1	1939-1943	M.I.T. Solar House No.I, Cambridge, Mass.	500 Labora-tory	640, 45° tilt, covered by 3 glass panes	Sensible heat: water 17,400 gal.	Water	Air
2	1947-1948	M.I.T. Solar House No.II, Cambridge, Mass.	720 7-section lab facing south	1024, vertical south wall, 7 different types @32 sq.ft. each	Various, including no storage	Various	Air
3	1948-1953	M.I.T. Solar House No.III, Cambridge, Mass.	600 as modified as a dwelling	640, 57° tilt	Sensible heat: water 1200 gal under insulated roof. Electric resistance booster.	Water	Air
4	1939-1951	M.I.T. Solar House No.IV, Cambridge, Mass.	1450 2-story	640, 60° tilt, 60 panels: 0.025 black Al, 3/4 dia. Cu tubes @5 in., 2 glass panes, fiberglass insulation, 43% efficiency	Sensible heat: water 1500 gal. Also 275 gal back-up, oil-heated to 135-150 F. Adequate for 3 cloudy days.	Water	Air
5	1945-1947	Lof House Boulder, Colo.	1000 Existing bungalow	465, 29° tilt, overlapping glass plates on sloping roof	Sensible heat: gravel 7 cu. yd., 8-9 ton in bin.	Air	Air
						Loops can be combined	
6	1955	U.S. Forest Service Desert Grassland Sta. Amado, Ariz.	672 Existing bungalow	335, 53° tilt, black cloth screens under glass pane, next to house	Sensible heat: gravel 90 cu.yd., 65 ton in bin next to house. Insulation: 4"conc. floor, 7"conc. walls, 8"rockwool ceiling. Stores 1.35×10^6 Btu between 140 and 90F for 10 average days.	Air	Air
						Loops can be combined. Ducts above ground	
7	1955-1954	Solar Heated Office Building, Albuquerque, N.M.	4800 Single story office building	750, 60° tilt, covers south wall; black Al plate, Cu tubes behind window glass pane	Sensible heat: water, 6000 gal underground insulated tank	Water	Water in floor & ceiling panels, 90-110F
8	1958	Lof House, Denver, Colo.	2050 Single story & partial bsmt.	600, 45° tilt, 2 staggered sections 2 x 25 ft. on roof, overlapping glass plates, 33% efficiency	Sensible heat: 2-1/2" gravel 230 cu.ft., 11 ton, 2 fiberboard drums, 3 ft. dia., 16ft high from bsmt. to roof	Air	Air
						Loops can be combined	
9	1958	ASHAE House Phoenix, Ariz.	Single story with central court	700, tiltable louvers, covers court & two patio roofs	Sensible heat: water 2000gal, 8.5 ton, underground tank	Water	Air (Heat Pump when water not hot enough)
10	1959	Solar Energy Laboratory, Univ. of Ariz. Tucson, Ariz.	1600 Single story adobe-type home	1600, 15° tilt, integral with roof green Cu sheet & tubes no glass, 23% efficiency	Sensible heat: water 4400gal. in 2 sections which may have ΔT=10F. Insulated above ground	Water	Water 110F in ceiling panels covering all rooms
11	1959	4 Solar Heated Homes Washington, D.C.	1500	840, on roof & abutting walls, black corrugated metal under glass & plastic film	Sensible heat: water(1500 gal) and gravel(50 ton). Gravel acts as storage and insulation	Water 135F max. temp.	Air
12	1946-1953	Telaga - Richard - Peabody House Dover, Mass.	1456 Single-story house collector surface on top face of 2nd story	720 sq.ft., black galvanized plate, 2 glass covers, 3 3/8 in. air duct, 40% efficiency	Latent heat: $NaSo_4 \cdot 10H_2O$, 470 cu ft, 21 ton in 5 gal drums in 3 closet bins. Heat exchange surface 2400 sq ft. Stores 4.7×10^6 Btu, adequate for 5-7 cloudy days.	Air 3 fans @1100 cfm	Air 6 fans @1100 cfm, 1/10 watts
						Loops can be combined	

Reproduced from best available copy.

Figure J-13 (Continued)

No.	Location Degree-Days Latitude	Performance: Heating	Performance: Cooling	Cost: Installation	Cost: Operation	Remarks
1	5900 42°N	Stored summer heat for winter use inefficient, storage too large. Heat loss 10,500 Btu/hr @ 0°F				Collector tilt not favorable to winter sun. Theoretical analysis confirmed.
2	Same					Louver & shade operation unreliable. Converted to #3.
3	Same	75% of space heat from sun. 181 sq.ft windows facing south. Heat loss 20,000Btu/hr @ 0°F				Collector framed in wood which cracked from overheating. Destroyed by fire in auxiliary oil heater.
4	Same	90% of space heat from sun. Attempted to collect 77% of insolation. Heat loss 30,000Btu/hr @ 0°F	Refrigerator cools 150 gal water tank to cool living room.			Hot water also supplied from thermal storage. In summer all solar energy used for water heating.
5	5500 40°N	20-25% of space heat from sun. Auxiliary gas furnace, hot air.				Insufficient insulation, leaky dampers. Initially high rate of collector glass breakage.
6	525 for January 23°N	No auxiliary heat needed. System was overdesigned	Single porous cloth over collector. Cool night air & 20°F sky radiation. Comfort equiv. to evap. cooling.....not up to A/C standards	$4000. Should cost $2000/$3000 for future models	$42/year. Equivalent bottled gas cost $80/yr.	Conventional heating unit $700 installed. Cannot amortize solar unit thru operating savings. May become economical if hot water & cooling systems are incorporated. Storage should be under house, not next to it; lose 25% of heat collected. Outdoor ducts awkward & unsightly.
7	4400 39°N	Heat pump booster. Storage for 3 days, thin need city water on cold side of pump.	7.5 ton heat pump evap. cooling to air, for low loads evaporator chills water without heat pump.	$17,400 ($4/sq ft), $58,500 ($13.60/sq ft) for building	First season heating: $75. Would cost $318 by heat pump, $163 by natural gas.	See item 9. May use tank to store "coolness" by running heat pump at night.
8	5700 40°N	26% of space & water heat from sun. Attempted collection of 72% of insolation.			Saved $80 natural gas per yr, could be increased to $100-130 by redesign. Needed $60 more power to drive fan	Auxiliary gas heater. Collector air passes thru 80 gal hot water tank before reaching storage or rooms.
9	1500 28°N	Heat pump booster, see Remarks.	Heat pump cooled by water from aerated swimming pool.			Heat pump is part of solar heating system, not an auxiliary. It extracts heat from water storage.
10	1800 25°N	Heat pump booster 1.5 hp, see Remarks. 65% of space heat from sun. 435 sq ft 2-pane windows. Heat loss 12,000 Btu/hr @ 30°F.	Same as heating system. Heat rejection up to 54,000 Btu per night from 70F water.		Heating & cooling: $500 kWh/yr: $215. Gas heat & electric A/C would cost $400	See Remarks, Item 9. Heat pump operates between 2 tank sections: 115/105F winter, 70/80F summer, ± 3F. Comfortable.
11	4000 39°N	95% of space heat from sun. Auxiliary oil heater used 50 gal/one season.	Uses same system as for heating. Water runs over bare metal roof & cools by evap., convect., & rad.	Simple design. Claim low cost.	Annual fuel saving: $150-200.	
12	6000 + [illegible]°N	First season 100% of space heat from sun, [illegible] heating loss. Collector yields 3.5x10⁶ Btu/day. Heat loss 9500 Btu/degree-day.		Materials only: Collector $950 Storage 635 Ducts, fans, Controls 1250 Total $3000 Mass produced unit cost est. $2450, conventional unit $3200.	Cost saving est. $200/yr. Amortized over 15 yr. Returns 22 years with $200/yr savings. 40 yr with $200/yr.	House enlarged in 1953. Heating system replaced. 170 sq ft windows add 10^6 Btu/day in winter.

Figure J-13 (Continued)

Reproduced from best available copy.

NO.	YEAR	HOUSE LOCATION	HOUSE SIZE (Sq. Ft.), TYPE	SOLAR COLLECTOR SIZE (sq. ft.), TILT, TYPE	THERMAL ENERGY STORAGE	LOOPS: COLL. TO STORAGE	LOOPS: STORAGE TO SPACE
13	1953	Solar Heated House, State College, N.M.	1100 1-1/2 stories	457, 45° tilt, facing S & SW Black steel plate, glass cover	Latent heat: $NaSO_4$ • 10 H_2O (Glauber salt) 2 ton in 5-gal cans. Stores $.5 \times 10^6$ Btu.	Air	Air
14	1959 1960	Solar Heated Laboratory, Princeton, N.J.	1200 Single story	600, vertical, black sheet metal, 2 glass covers efficiency 46%	Latent heat: $NaSO_4$ • 10 H_2O (Glauber salt) 275 cu ft, 12 ton	Air	Air
15	1950-1955	Solar Heated House, New Haven, W.Va.		112, 59° tilt, glass covered evaporator plate, 1 inch away from 3-inch insulation	None		Heat Pump
16		House, Japan	2460 2-story	1410, 15° tilt, on roof, corrugated sheet metal, no cover	Sensible heat: water 9600 + 2700 gal. concrete tanks in bsmt.	Water 55-80F	Water in ceiling panels
17		Laboratory, Japan	680	330, 35° tilt, corrugated sheet metal, no cover	Sensible heat: water 1480 + 1460 gal. tanks	Water 55-90F	Air
18		Capri Italy	1940 2-story	320, metal, glass covered, in walls	Sensible heat: water 800 gal.	Water	Water (Radiators)
19	1970	Solar Heated House, Cadillo, France	810 Single story steel	520, vertical, covers 40'x13 ft south wall except for 13x9 ft door opening. 2 glass panes and air space in front of conc. storage block	Sensible heat: concrete 2-ft thick wall behind entire collector, 100 ton, insulated on back facing house. 40,000 Btu/°F.	None	Air
20	1964-1966	Test Houses Edison Electric Institute, Phila., Pa. (Chemplank)	Various, 10 homes of employees of Phila. Elect. Co.	None	Sensible & latent heats: sodium hydroxide. Operate between 265 and 900F, melts at 540F. 8.37 cu ft, 862 lb. Add 8-inch insulation and fans, total unit: 63 cu ft, 1950 lb.		Air at 155F
21	1962-1963	Demonstration House, (Proposed) Allentown, Pa.	3-story plus bsmt. stone & clapboard	None	Latent Heat: inorganic salt, melts at 154F. 27 cu ft, 2400 lb plus 2-inch insulation: 49 cu ft. $.6 \times 10^6$ Btu storage; 60,000 Btu/hr.		Water
22	1955	Great Britain	Room units	None	Usually concrete brick. 16-60 kwh heat plus 6 kwh water (75 gal) 24x24x2 inch incl. fiberglass insulation		Air
23	1955	W. Germany	Room units	None	Usually magnesia block. 16-60 kwh, 330-992 lb. 6-14 cu ft, 12 lb/sq ft approx. floor load.		Air

Figure J-13 (Continued)

Reproduced from best available copy.

No.	Heating Degree-Days, °C-days (°F-days) Location	Performance: Heating	Performance: Cooling	Cost: Installation	Cost: Operating	Remarks
13	32°N	50.6 % of space heat from sun, although ext. stg. less, collection is .5x10⁶ Btu/day, 25% larger than req'd.				Segregation of Glauber salt progressively decreased storage capacity. Can be avoided by proper design.
14	5100 40°N	No auxiliary heat needed. Typical Jan. heat load 12,000 Btu/hr.				
15	39°N	Collected 60% of insolation. Jan. 10-20, 400 Btu/ft² day collected: 3.4% of insolation.				On warm days/March, April ambient air also heats refrigerant; heat collected may exceed total insolation.
16 & 17		70-75% of space heat from sun. Collected 22% + of insolation.	Use same system as for heating. Water runs in roof corrugations which radiate heat at night			3-hp heat pump operates between two reservoirs, cold side preheated by sun.
18	40°N	Designed for 50% of space heat from sun.				Auxiliary gas or electric resistance heater
19		Approx. 50% of space heat from sun.				Collector & storage are integral. Air moves upward between glass & concrete block.
20	4500 40°N	Delivers 30,000 Btu/hr into 310 cfm air. Heat loss of unit, 3000 Btu/hr charged, 2000 Btu/hr discharged. Satisfactory performance. Auxiliary heat pump.		Prototypes cost $2900, 20% of estimate. Mass produced factory price $275, installed: $493= $1.50/1000 Btu.	Use off-peak electric power to charge, discharge during peak hours.	Contains; welds leaked; caustic soda, dangerous. High temp. & toxicity are disadvantages. Units removed after 2 years.
21	5000 41°N	Stored heat only: 1°F drop in room air in 12 hr with 20-34°F ambient, 1°F drop in 10 hr with 15-19°F ambient. Recharge in 10-12 hr.	None		Same as above. 18 hr charge with 1 11kw & 1 10 kw heater	
22		Heating element up to 140°F, brine up to 200°F 240V.		$56 (1961) for 10 kWh. Approx. $1/1000 Btu.	Same as Item 19.	In 1973, at least 5 firms manufactured these units. Fifty-four than 1/2 million in service then cutting peak [illegible] kw
23		200/300?			Same as Item 19.	At least 3 firms manufactured these units.